State of Alaska Epidemiology **Bulletin** Recommendations and Reports

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Assessment of the Potential Health Impacts of Climate Change in Alaska

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Background

Over the past century, the air and water temperatures in Alaska have warmed considerably faster than in the rest of the United States. Because Alaska is the only Arctic state in the Nation, Alaskans are likely to face some climate change challenges that will be different than those encountered in other states. For example, permafrost currently underlies 80% of Alaska and provides a stable foundation for the physical infrastructure of many Alaska communities. As has already been seen in numerous villages, the groundcover that overlies permafrost is vulnerable to sinking or caving if the permafrost thaws, resulting in costly damage to physical infrastructure. The reliance on subsistence resources is another contrast to many other states. Many Alaskans depend upon subsistence harvests of fish and wildlife resources for food and to support their way of life. Some Alaskans report that the changing environment has already impacted their traditional practices.

Many past efforts to characterize the potential impacts of climate change in Alaska have focused primarily on describing expected changes to the physical environment and the ecosystem, and less on describing how these changes, in addition to changes in animal and environmental health, could affect human health. Thus, a careful analysis of how climate change could affect the health of people living in Alaska is warranted. The Alaska Division of Public Health has conducted such an assessment using the Health Impact Assessment (HIA) framework; the assessment is based on the current National Climate Assessment (NCA) predictions for Alaska.

The document is intended to provide a broad overview of the potential adverse human health impacts of climate change in Alaska and to present examples of adaptation strategies for communities to consider when planning their own response efforts. This document does not present a new model for climate change in Alaska, and it does not offer a critique of the NCA predictions for Alaska.

Finally, while this assessment is focused on the potential adverse health impacts of climate change in Alaska, it is important to note that there will likely be some beneficial health impacts of climate change in Alaska as well. For example, warmer temperatures might be more conducive to a longer growing season and growing a wider range of agricultural crops, resulting in increased food security in some areas. Warmer winter temperatures might also lead to fewer injuries and fatalities related to cold temperatures.

Big Picture Overview

What is already known about this topic?

Alaska is experiencing changes in climate, and temperatures in the state have warmed faster than the rest of the United States. Climate change has already affected human health in Alaska and additional impacts are likely to occur.

What is added by this report?

The impacts of climate change in Alaska have been well documented in historical, environmental, and regional contexts, but little has been published on the range of human health impacts statewide. This report provides a broad assessment of the potential adverse human health impacts of climate change in Alaska.

This report is also intended to serve as a resource for communities to determine which adverse impacts of climate change are most likely to affect their residents and to help communities develop their own adaptation strategies for climate change.

Climate Change Predictions for Alaska

This HIA is based on assumptions and projections provided in the third NCA report and supporting documents, including Volume I of the fourth NCA. The NCA frequently refers to Scenario A2, which assumes increasing concentrations of greenhouse gases in the Earth's atmosphere and has been considered as a plausible climate scenario in multiple climate assessments. This HIA presents a general picture of what climate conditions might look like in Alaska, based on Scenario A2, as well as additional simulations presented by other agencies. Highlights of these predictions are below.

Temperature: Compared to 1971–1999, Alaska's average annual temperature is expected to be 2°–4°F higher in 2050 and 8°–9°F higher in 2100. Moreover, projections indicate that as temperatures increase, near-surface permafrost will disappear from much of Alaska by 2100 and the permafrost boundary will move hundreds of miles northward by the end of the century.

Precipitation: The average annual precipitation is predicted to increase by 15%–30% by 2100, compared to the reference period of 1971–1999. Snowfall amounts are predicted to decrease, but more areas will likely become wetter due to increased duration and volume of rainfall. Much of the increased precipitation is likely to evaporate because of increased temperatures. Extreme storms and extreme precipitation events may also increase.

Sea Ice Extent: Summer sea ice is predicted to disappear in the Chukchi Sea by 2050, and winter sea ice could decrease by 50% in the Bering and Chukchi Seas by the end of the century.

Climate Change and Potential Health Impacts in Alaska

The Alaska Division of Public Health typically assesses health impacts using health effect categories (HECs), which have been developed to identify the full spectrum of possible health impacts related to a specific scenario. Examples are provided below of what has been observed in each of these categories and what may be expected for the next 20–50 years, given the climate change predictions for Alaska (note: a wide range of examples of potential adverse health impacts of climate change in Alaska that are not provided in this executive summary are presented in the full document). It is important to note that climate-associated health impacts on communities are magnified by additional social and economic stresses that are not reviewed in this HIA.

Mental Health and Wellbeing: Climate change can affect mental health by causing solastalgia, the distressing sense of loss that people experience as a result of unwanted environmental changes that occur close to one's home, and associated pathologies including anxiety, depression, and post-traumatic stress disorder that can result from acute events such as fires, floods, and storm surges, and more protracted changes such as thawing permafrost and coastal erosion. These effects tend to disproportionately impact those living in low-resource settings, including indigenous groups. Psychosocial distress and its associated comorbidities will likely continue to increase in Alaska as communities experience unwanted changes in their environment.

Accidents and Injuries: Accidents and injuries due to extreme weather events, such as droughts, floods, and storms, are predicted to increase with climate change, and some reports suggest that such increases are already occurring. Flooding is a particular concern of extreme precipitation events and coastal storms, as floods are the second only to heat as the deadliest of all weather hazards in the United States. Extreme precipitation events can also lead to fatal- and non-fatal injuries due to mudslides, debris flow, and avalanches. Moreover, motor vehicle accidents may increase as thawing permafrost and the freeze-thaw cycles in the active layer of soil can cause damage to the transportation infrastructure in Alaska, which includes highways, railroads, and airstrips.

Potential Exposure to Hazardous Materials: A warming climate is predicted to lead to more frequent and larger fires in the Arctic. Over 5 million acres burned in Alaska in 2015, making it one of the worst recorded fire seasons ever. Fairbanks has had multiple air quality advisories in recent years due to hazardous conditions from wildfire smoke. As large wildfires increase, more poor air quality events are likely to occur, potentially leading to exacerbations of pre-existing respiratory and cardiovascular illnesses.

Food, Nutrition, and Subsistence Activity: Diminished food quality and quantity as well as changing food distribution and subsistence patterns are predicted to continue to arise from climate change. In Alaska, for example, hunters report thinning sea and river ice, which makes harvesting wild foods more dangerous. Storing and harvesting wild foods may also become more difficult with increased temperature and precipitation.

Infectious Diseases and Toxins from Microorganisms: Increasing temperatures and changing weather patterns could have many implications for infectious diseases in Alaska, especially waterborne and vectorborne diseases. For example, increased water temperatures could lead to more outbreaks of *Vibrio parahaemolyticus* gastroenteritis. Additionally, increased air temperatures could facilitate the northern spread of insects that can transmit West Nile Virus and Lyme disease.

Non-communicable and Chronic Diseases: Climate change is predicted to affect allergies and respiratory health as higher temperatures and changes in precipitation influence the abundance, seasonality, and distribution of aeroallergens (e.g., plant pollen). As a result, rates of allergic rhinitis (hay fever) and asthma are predicted to increase due to changes in aeroallergen concentrations. Warmer average winter temperatures in Alaska might have already contributed to an increase in patients seeking health care due to reactions from insect (e.g., yellowjacket) stings.

Water and Sanitation: Climate change brings a new complication to the challenge of addressing Alaska's existing water and sanitation disparities. Water and sanitation infrastructure damage has already occurred in some communities due to coastal erosion, thawing permafrost, storm surges, and flooding. Further damage to drinking water, wastewater, or storm water systems could adversely impact human health by way of facilitating waterborne diseases and decreasing the availability and quality of drinking water.

Health Services Infrastructure and Capacity: Thawing permafrost, erosion, wildfires, and flood events could damage health care infrastructure and decrease access to care by making travel to clinics more challenging.

Key Potential Adverse Health Impacts by Health Effect Category

One initial step that local communities can take to prepare for climate change is to identify and prioritize the potential health impacts that will be most relevant to their community and, for each identified impact, determine the expected timing and magnitude of the effect. Examples of criteria that could be used for this application include (a) potential time to impact, (b) geographic extent of the impact, (c) the number of people directly impacted, (d) the number of people impacted who might experience serious health problems, and (e) resources needed to adapt to the impact. These criteria can then be summarized and presented in a simplified visual format such as a tiered and color-coded table. Next, communities can create a table that displays what the potential adverse health impacts of climate change might look like in their community for each health effect category to help prioritize adaptation strategies and resource needs (an example of what such a table might look like on a statewide basis is presented in the full document).

Summary of Monitoring and Adaptation Recommendations

The monitoring recommendations provided in this HIA are intended to help characterize the adverse health impacts of climate change over time. Monitoring indicators and resources are listed to help decision-makers and other stakeholders develop surveillance strategies and identify agencies currently collecting the relevant health and environmental data. Examples of proposed monitoring indicators include cases of selected infectious diseases, hospitalizations and deaths due to climate-related events (e.g., flooding, storm surges, wildfires), and changes in subsistence food consumption and food security. Examples of monitoring resources provided include the Scenarios Network for Alaska + Arctic Planning (SNAP) for community profiles on observed and projected temperatures; the Local Environmental Observer (LEO) Network for postings by local observers and topical experts about unusual animal, environment, and weather events; and the Alaska Trauma Registry (ATR) for injury trends. Where possible, this HIA identifies monitoring strategies that have been developed and tested by other state, federal, and international entities.

The adaptation recommendations provided in this HIA are intended to reduce morbidity and mortality from climate-related causes. Adaptation as it relates to climate change is defined by the Intergovernmental Panel on Climate Change as the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities." Examples of proposed overarching adaptation strategies include developing local and statewide climate change advisory groups, assessments, and adaptation plans; offering community members opportunities to relay their concerns about climate change and propose solutions; including human health in community vulnerability assessments for climate change; and assuring an adequate workforce capable of performing climate change research, surveillance, and adaptation. More specific adaptation strategies are also provided, such as reviewing architecture and engineering designs to ensure that plumbing infrastructure can withstand changes to the underlying permafrost, and if not, consider ways to address the problem; supporting successful community-based mental health wellness programs; and developing community response plans for wildfires.

1.0 INTRODUCTION AND OVERVIEW

1.1 Climate Change Overview and Description

Climate change refers to both local and global alterations in climate, as well as the secondary effects of new climate conditions (such as decreasing sea ice). Rising temperatures, changes to precipitation, and increased frequency of extreme weather events are only a few of the commonly discussed features of climate change (IPCC, 2012). Each of these features has implications for ecosystems and human health (Luber et al., 2014; NCA, 2014).

1.2 HIA Overview

This Health Impact Assessment (HIA) provides a review of potential adverse human health impacts related to climate change in Alaska. It will (1) provide a broad overview of the wide range of potential adverse climate change impacts on human health in Alaska, (2) present the most current climate change information, to the extent possible, and (3) present examples of strategies for communities and decision-makers to consider when planning their own actions in response to climate change.

1.3 Legal Requirements for Health Impact Assessment (HIA)

The State of Alaska developed an HIA Toolkit to guide HIA practitioners in the state (referred to as Alaska HIA Toolkit; ADHSS, 2015). This Climate Change HIA represents a non-traditional HIA for Alaska (in that it does not focus on a proposed resource development project), though it still uses the HIA Toolkit as a guiding framework. As with traditional Alaska HIAs, this document and its related recommendations are not legally binding for any agency.

1.4 Purpose of Document

This report is intended to identify available information and enhance knowledge on climate change and how it might negatively impact human health in Alaska. It uses the structure of HIA to characterize and forecast the potential adverse health impacts of climate change in the state. A review of this type is especially important because there has not been a statewide comprehensive review or extensive discussion of potential human health impacts of climate change in Alaska. This report will be useful for communities and decision-makers in determining how to prioritize monitoring and adaptation strategies related to climate change.

1.5 HIA Framework and Methodology

1.5.1 HIA Definition

Health Impact Assessment is a combination of procedures, methods, and tools by which a policy, program, or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population.

1.5.2 HIA Methods

Using methodology presented in the Alaska HIA Toolkit (ADHSS, 2015), this HIA

- Reviews components of climate change based on climate change predictions for Alaska,
- Reviews the physical and general environmental setting of predicted changes,
- Identifies potential adverse health impacts using a set of defined health effect categories (HECs),
- Provides a perspective of the wide range of potential climate change impacts on human health in the state, and
- Provides examples of monitoring recommendations and adaptation strategies tied to potential health impacts.

1.5.3 HIA Scope

This HIA reviews the potential health impacts of climate change in Alaska primarily based on the following information:

- State of Alaska (SOA) databases and reports
- The National Climate Assessment (NCA) and associated documents
- The United States Global Change Research Program's (USGCRP) Climate and Health Assessment, 2016
- General methodologic parameters developed by the Alaska HIA Toolkit

1.5.3.1 Areas Outside the Scope of the HIA

While this HIA is focused on the potential adverse health impacts of climate change in Alaska, it is important to note that there will likely be beneficial health impacts of climate change in Alaska as well. For example, warmer temperatures could be more conducive to a longer growing season and growing a wider range of agricultural crops, which would increase food security in some areas. Warmer winter temperatures might also lead to fewer injuries and fatalities related to cold temperatures. That said, the instances of potential benefits of climate change are likely to be limited in number and smaller in magnitude than the adverse consequences (e.g., the increase in food security from the ability to grow new crops is likely to be smaller than the decrease in food security resulting from the decreased availability of some subsistence resources; USGCRP, 2016). Local communities can maximize potential positive health impacts of climate change by prioritizing their adaptation strategies and taking timely action steps.

1.5.3.2 Health Effect Categories (HECs)

The Alaska-specific HECs are a standard set of health effect categories that have been developed and discussed in the Alaska HIA Toolkit (Table 1). HECs have been developed to identify the full spectrum of possible health impacts related to a specific project or, in the case of this HIA, a set of climate change predictions. This climate change HIA adapted the Alaska HECs to better suit a discussion of climate change. As such, the Social Determinants of Health—the conditions in which people are born, grow up, live, work, and age (USDHHS, 2017)—are discussed as a constellation of factors that have implications within each HEC, rather than as a separate HEC, and Mental Health and Wellbeing was added as a new HEC. Finally, the advantage of the HEC structure is completeness, the disadvantage is occasional redundancy as some of the HECs overlap (e.g., mental health and wellbeing can be related to food, nutrition, and subsistence activities).

Table 1. Health Effect Categories

Health Effect Category	Pathway Description
Mental Health and Wellbeing	This category pertains to outcomes and determinants related to mental health, substance use, social exclusion, psychosocial distress, historical trauma, family dynamics, economic stressors, and social support systems. The key outcomes considered are increases and decreases in psychosocial distress and its associated comorbidities, adverse health behaviors (such as substance abuse), anxiety, depression, and suicide.
Accidents and Injuries	This category pertains to health outcomes and determinants related to accidents and injuries. The key outcomes considered are increases and decreases in intentional and unintentional injuries with fatal and nonfatal results. The key determinants in this category include items such as the presence of law enforcement, traffic patterns, alcohol involvement, distance to emergency services, and the presence of prevention programs.
Exposure to Potentially Hazardous Materials	This category pertains to health outcomes and determinants that may arise from exposure to hazardous materials. The key health outcomes considered are increases and decreases in documented illnesses or exacerbation of illnesses commonly associated with pollutants of potential concern. These may be mediated through inhalation, ingestion, or physical contact.
Food, Nutrition, and Subsistence Activity	This category pertains to health outcomes and determinants related to food security, dietary choices, and the consumption of subsistence foods. The key health outcomes considered are nutrient levels, malnutrition or improvements in nutrient intake, and the subsequent increases or decreases in related diseases. The key determinants include diet composition, food security, and the consumption of subsistence foods.
Infectious Diseases and Toxins from Microorganisms	This category pertains to health outcomes and determinants that result from infectious diseases. The key health outcomes include rates of increase or decrease for a range of infectious diseases, such as sexually transmitted infections (STI), respiratory illnesses, or skin infections. Important health determinants may include immunization rates and the presence of infectious disease prevention efforts.
Water and Sanitation	This category pertains to changes to access, quantity, and quality of water supplies.

Table 1. Health Effect Categories

Health Effect Category	Pathway Description
	Key determinants reviewed may include distance to clean water, water fluoridation, indoor plumbing, water treatment facilities, adequate volume of water resources, and the existence of community facilities, such as a washeteria and/or community.
Non-communicable and Chronic Diseases	This category pertains to health outcomes and determinants related to chronic disease. Important outcomes include increases or decreases in mortality and morbidity rates of cancer, cardiovascular and cerebrovascular diseases, diabetes, respiratory diseases, and mental health disorders. Key determinants for chronic diseases may include smoking rates, rates of alcohol and drug abuse, physical activity levels, presence of recreation centers, as well as cancer screening rates.
Health Services Infrastructure and Capacity	This category pertains to health outcomes and determinants related to health care access and health care infrastructure. Important outcomes include the increase or decrease in the number of medical evacuations (medevac), clinics or hospital visit trends, health expenditures, and medication usage. Health determinants may include distance to health facilities, medevac facilities/aircraft, the presence of community health aides, and the frequency of visits to the area by health care providers.

2.0 OBSERVED AND PREDICTED CLIMATE CHANGE

2.1 Climate Change Defined

What is climate?

Climate is the long-term average variation in weather measured over an extended period (i.e., several decades; NWS, 2009).

What is weather?

Weather is the state of the atmosphere in terms of wind, temperature, cloudiness, humidity, etc. at a given time. Climate refers to the average weather conditions over a longer period of time (NWS, 2009).

What is climate change?

According to the U.S. Environmental Protection Agency (EPA), "climate change refers to any substantial change in measures of climate (such as temperature or precipitation) lasting for an extended period (decades or longer)" (EPA Climate Change Indicators, 2016). It is important to note that climate change is *not* synonymous with global warming. Global warming refers to the average increase in temperature of the atmosphere, which is just one potential indicator of climate change.

General Theory of Climate Change

Climate change is influenced by human activities and natural processes (IPCC, 2014; USGCRP, 2017). Normally, when solar radiation reaches the Earth, some is reflected by the atmosphere, but most is absorbed and warms the Earth's surface. Some of the absorbed solar radiation is re-emitted as infrared radiation and absorbed by greenhouse gas molecules in the atmosphere (e.g., water vapor, CO_2, methane, nitrous oxide, and chlorofluorocarbons [NASA, 2017]), which re-emits the radiation back towards the Earth, warming the Earth's surface. As the Earth's atmosphere changes and greenhouse gas emissions increase, less solar radiation can escape, which leads to further warming. This extra heat then impacts various components of climate (e.g., air and ocean temperatures, weather patterns; NCA, 2014).

2.2 Climate Change Indicators

This HIA defines seven key indicators most relevant to climate change in Alaska. These indicators are tied to the potential effects of climate change and facilitate tracking these effects to obtain a better picture of the various components of climate change in Alaska. This climate change HIA is focused on the following indicators:

- Temperature
- Precipitation
- Weather patterns
- Sea ice
- Glaciers
- Permafrost
- Sea levels

A detailed discussion of these indicators and how they are measured can be found in Appendix 1.

2.3 Evidence of Climate Change in Alaska

Globally, temperature trends show evidence of a warming planet. The annual average global surface temperature has risen at an average rate of 0.15°F per decade since 1901 (EPA Climate Change Indicators, 2016). Ocean temperatures, precipitation, and sea levels have also increased globally. A more detailed discussion of the changes among the indicators on a global and national scale can be found in Appendix 2.

Trends in the Arctic related to climate change are typically more pronounced than in other parts of the world. Arctic regions are predicted to see rapid and substantial climate changes (ACIA, 2005). Over the past several decades in Alaska, the only Arctic region in the United States, temperatures have risen, precipitation has increased, sea ice has declined, and permafrost has thawed at an increasing rate (EPA Climate Impacts, 2016; Stewart et al., 2013; Richter-Menge et al., 2017).

2.3.1 Temperature

Alaska warmed twice as fast as the rest of the United States from 1949–2011 (EPA Climate Impacts, 2016; Chapin et al., 2014). While there is substantial variation in year-to-year temperatures, clear trends exist (Stewart et al., 2013). Overall, Alaska now experiences more extremely hot days (warmest 1% of daily high temperatures since 1950) and fewer extremely cold days (coldest 1% of daily low temperatures since 1950; NCA, 2014; Stewart et al., 2013; Blunden & Arndt, 2017). Statewide, the average annual air temperature has increased by 3°F and the average winter temperature has increased by 6°F since the 1950s (Chapin et al., 2014). Much of the warming has occurred in the winter and spring (Stewart et al., 2013). Alaska had record-setting warmth during the cold season of 2015–2016 (from October through April). Average temperatures during the 2015–2016 cold season exceeded the period-of-record (1925–2016) mean by more than 8.4°F; the Interior region experienced the greatest increase in temperatures (Stewart et al., 2013; Walsh et al., 2017).

2.3.2 Precipitation

Long-term trends show average precipitation from 1945–1965, followed by approximately 15 years of below average precipitation totals. Subsequently, the average annual precipitation has increased statewide by approximately 10% in recent decades (Stewart et al., 2013).

Extreme precipitation events, defined as the heaviest 1% of 3-day precipitation totals for each calendar year, have increased in the spring in the southeast and west-central portions of the state. The northern region has experienced a decrease in extreme precipitation events in all seasons except fall. All regions in Alaska, except the Arctic, have seen an increase in extreme precipitation events during the summer months (Stewart et al., 2013).

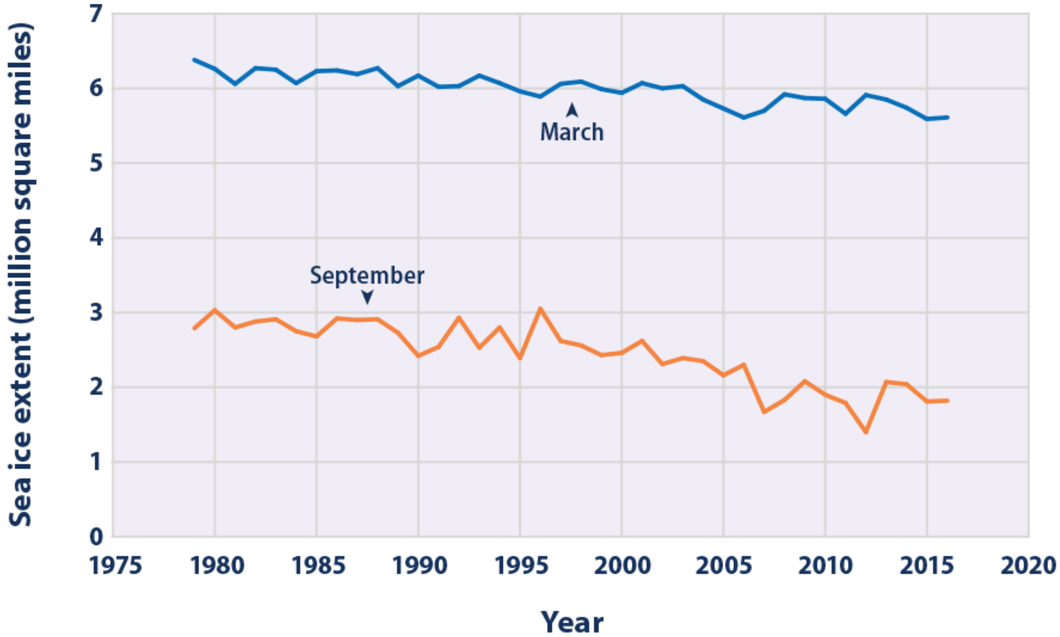
2.3.3 Weather Patterns

An analysis of Alaska storm information from the National Centers for Environmental Predictions storm track database during 1953–2010 showed no significant change in the overall frequency of strong storm events. Along the northern and northwestern coasts, however, strong storm events have increased in the summer and fall months when there is no protective sea ice cover (Stewart et al., 2013).

2.3.4 Sea Ice

Sea ice extent has declined substantially in the Arctic and some of the fastest loss has been along the Alaskan coast (USGCRP, 2017). Based on satellite-based sea ice records, which began in 1979, end of summer sea ice from 2007–2012 was lower than any prior time (Stewart et al., 2013). The average annual Arctic sea ice extent has decreased 3.5–4.1% per decade since 1979 (USGCRP, 2017). In 2012, the September sea ice coverage was roughly 50% less than in the 1980s (Figure 1. ; EPA Climate Change Indicators, 2016). The March 2017 sea ice extent was approximately 8% less than the 1981–2010 average for that month (Richter-Menge et al., 2017). The September 2017 sea ice extent was approximately 25% less than the 1981–2010 average for that month. The sea ice is also younger and thinner (factors that make sea ice more vulnerable to summer melt) than any time on record (Chapin et al., 2014; Stewart et al., 2013). The greatest reduction in sea ice has been in the Pacific side of the Arctic. Researchers believe that increased heat inflow through the Bering Strait from the North Pacific is a key contributing factor to the retreat of sea ice since the 1980s (Stewart et al., 2013).

Figure 1. March and September Monthly Average Sea Ice Extent, 1979-2016



Data source: NSIDC (National Snow and Ice Data Center). 2016. Sea ice data and image archive. Accessed October 2016. http://nsidc.org/data/seaice_index/archives.html.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Source: EPA Climate Change Indicators, 2016

2.3.5 Glaciers

Alaska is experiencing the fastest loss of glacier ice on Earth (NCA, 2014). According to the National Climate Assessment, "from 2005 to 2010, Alaskan glacier losses made up one-third of the world's ice sheet losses, even though Alaska has 20 times fewer ice-covered areas than Greenland" (NCA, 2014). Additionally, Alaska's glaciers lose approximately 75 gigatons of water each year, which contributes 0.008 inches to the global annual sea level rise as well as a relative sea level fall in some parts of Alaska, such as in the southeast, as the land in these glacial regions rebounds (Meier et al., 2007; Vaughan et al., 2013).

2.3.6 Permafrost

Permafrost is ground that remains frozen for a period of at least 2 consecutive years. It has an active layer, which thaws downward from the surface during warm seasons, and refreezes during the fall. Underneath the active layer is a stable layer that remains frozen; the depth of this layer depends on average annual temperatures, snow depth, soil properties, and ground slope (Stewart et al., 2013). Additionally, large quantities of organic carbon are stored in permafrost. As permafrost thaws, it can release greenhouse gases such as carbon dioxide (CO_2) and methane (Schuur et al., 2015).

Permafrost is critical for the basic existence of many communities and ecosystems in Alaska. Eighty percent of Alaska is underlain by permafrost, and seventy percent of this land is vulnerable to subsidence (caving in or sinking) if the permafrost becomes unstable (Chapin et al., 2014; Jafarov et al., 2012). As temperatures have increased, permafrost has begun to thaw. Since the 1970s, permafrost near the Arctic coast has warmed 4–5°F at the 65-foot depth (Chapin et al., 2014). In 2016, record high temperatures were observed at the 20 meter depth at all permafrost observatories on Alaska's North Slope, with the exception of Deadhorse (Blunden & Arndt, 2017; Ritcher-Menge et al., 2017).

2.3.7 Sea Levels

While sea levels have risen in much of the world, levels in parts of Alaska have fallen. Scientists believe the decrease in sea level is due to changing vertical tectonic motion. Large earthquakes in Alaska's recent history have also impacted sea level calculations (separate sea level trends are calculated using data from before and after the earthquakes in 1957, 1964 and 1988). There is considerable regional variability in current sea level trends in Alaska. For example, Yakutat, Skagway, and Juneau have recorded the largest decreases in sea level (-15 to -18 millimeters/year from 1975–2014). Sand Point, Prudhoe Bay, and Prince Rupert have experienced small increases in sea level (+0 to 3 millimeters/year from 1975–2014; NOAA Tides and Currents). There are limited tidal gages in Alaska (e.g., there are no tidal gages from Bristol Bay to Norton Sound) and thus there is considerable uncertainty in determining the relative changes in sea level statewide (USGCRP, 2017).

2.4 Climate Change Predictions for Alaska

This HIA is based on assumptions and projections provided in the third National Climate Assessment (NCA, 2014) and supporting documents including Volume I of the fourth NCA (Volume II was not yet available at the time of publication of this HIA; USGCRP, 2017). The NCA frequently refers to Scenario A2, which was released by the Intergovernmental Panel on Climate Change (IPCC, 2000); this scenario assumes increasing concentrations of greenhouse gases (e.g., water vapor, CO_2, methane, nitrous oxide, and chlorofluorocarbons [NASA, 2017]) in the Earth's atmosphere and has been considered as a plausible climate scenario in multiple climate assessments. This HIA presents a general picture of what climate conditions might look like in Alaska, based on Scenario A2, as well as additional simulations presented by other agencies. It is important to underscore the inherent difficulty in making climate change predictions due to a wide range of variables, including changes in emissions, population, economics, technology, etc. However, the use of such a scenario, where the potential changes of various indicators are predicted from the same set of climate model simulations, provides a consistent climate picture to forecast potential health impacts to a population (Stewart et al, 2013). A summary of the projections for Alaska, focusing on seven measurable climate indicators, is provided below (Table 2; refer to Section 2.6 for additional region-specific information). This document does not present a new model for climate change or contain any new data or analyses; rather, it is a review of existing literature.

Table 2. Summary of Climate Change Predictions for Alaska

Climate Change Indicator	Region*			
	Alaska (Statewide)±	Coastal#	Interior†	Northern‡
Temperature	• Increase of 2–4°F by 2050[2] • Increase of 8.6°F by 2085[1]	• Increase of 6–8°F by the end of the century[2] (least amount of warming in southeast AK)	• Increase of 8–10°F by the end of the century[2]	• Increase of approximately 10–12°F by the end of the century[2]
Precipitation	• Increase of 0–15% by 2035[1] • Increase of 10–35% by 2085[1] • Increased heavy precipitation events, amount indeterminate • Wetter winters and drier summers[4]	• Increase of 5–15% by 2035[1] • Increase of 15–35% by 2085[1] • Largest increases in northwestern coastal region, smallest increases in southeast AK[1,2]	• Increase of 0–5% by 2035[1] • Increase of 20–30% by 2085[1]	• Increase of 0–15% by 2035[1] • Increase of 25–35% by 2085[1]
Weather	• Increased storm intensity, amount indeterminate[3] • Change to winter storms is uncertain[2] • Increased length of summer[1] • Decreased length	• Increased storm intensity, amount indeterminate[3] • Change to winter storms is uncertain[2] • Fall freeze-up delayed by 40–60 days[1]	• Increased storm intensity, amount indeterminate[3] • Change to winter storms is uncertain[2] • Spring thaw date advanced by 2–3 weeks[1]	• Increased storm intensity, amount indeterminate[3] • Change to winter storms is uncertain[2] • Fall freeze-up delayed by one month[1]

Climate Change Indicator	Region*			
	Alaska (Statewide)±	Coastal#	Interior†	Northern‡
	of winter[1]		• Fall freeze-up delayed by 2 weeks[1]	
Sea Ice	• Virtually ice-free northern waters in late summer by 2040s[2. 5]	• Decrease of winter sea ice in the Bering Sea of more than 50% by the end of the century[1]	• N/A	• No summer ice in the Chukchi Sea by 2030–2050[1] • Decrease of winter sea ice in the Chukchi Sea of more than 50% by the end of the century[1]
Glaciers	• Continued glacier retreat, amount indeterminate[2]	• Continued glacier retreat, amount indeterminate[2]	• Continued glacier retreat, amount indeterminate[2]	• Continued glacier retreat, amount indeterminate[2]
Permafrost	• Near-surface permafrost will be lost entirely from large parts of the state by the end of the century[2] • Permafrost boundary will shift hundreds of miles northward by the end of the century[4]	• Permafrost-free by the end of the century[2]	• Significant permafrost degradation[1,2]	• Degradation of permafrost by the end of the century, but the smallest decreases in the state[2]
Sea Levels	• Increasing sea levels, amount indeterminate[3]	• Increasing sea levels, amount indeterminate[3]	• N/A	• Increasing sea levels, amount indeterminate[3]

[1]Stewart et al., 2013; [2]NCA, 2014; [3]UAF Sea Grant, 2014; [4]EPA Climate Impacts, 2016; [5]USGCRP, 2017

**The regions presented here were selected to remain consistent with the National Climate Assessment Reports and other supporting documents (e.g., Stewart et al., 2013). Change in indicator represents a change from baseline levels. Baseline data are presented in subsequent sections.*

±Predictions for Alaska overall; data presented often represent average predicted change for Alaska.

#The coastal region represents communities south of the Brooks Range and in proximity to the coast. In this document, the coastal region includes southeast (e.g., Juneau, Ketchikan, Sitka), south coast (e.g., Anchorage, Kodiak, Cordova), southwest (e.g., Bethel, Dillingham), and west-central (e.g., Nome, Kivalina, Kotzebue) portions of the state.

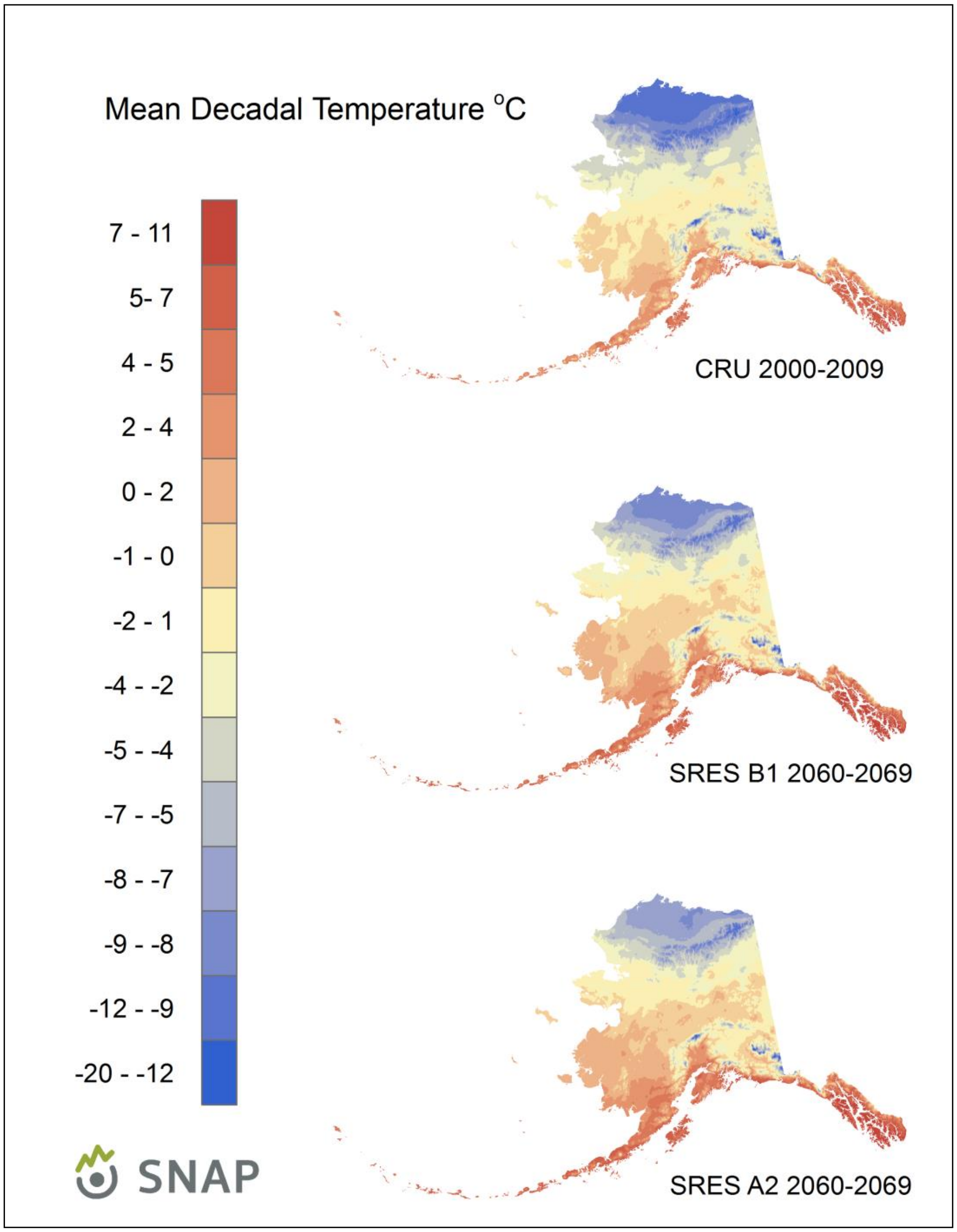
†The interior region is bounded by the Brooks Range and the Alaska Range; communities in this region include (among others) Fairbanks, Tanana, and Galena.

‡The northern region is bounded by the Brooks Range and the Arctic Ocean. Communities in this region include (among others) Utqiaġvik (formerly known as Barrow), Prudhoe Bay, and Anaktuvuk Pass.

2.4.1 Temperature

Recent models predict that compared to 1971–1999, Alaska's average annual temperatures will be 2°–4°F higher in 2050 and 8°–9°F higher in 2100 (Stewart et al., 2013). Compared to 2000–2009, from 2060–2069, northern and interior Alaska are expected to experience greater increases in mean decadal temperature than other regions in the state (Figure 2). These regions are predicted to increase by approximately 10°F. Statewide, mean winter temperatures are predicted to increase by approximately 4°F by 2035, 8°F by 2050, and more than 12°F by 2085 (Stewart et al., 2013; Walsh et al., 2017).

Figure 2. Mean Decadal Annual Temperature for Alaska, by Region



CRU: past data collected by the Climatic Research Unit; SRES B1: lower emissions scenario; SRES A2: higher emissions scenario. Source: NCA, 2014; Stewart et al., 2013

2.4.2 Precipitation

Annual precipitation is predicted to continue to increase in Alaska, particularly in northwestern Alaska. Models also predict that, compared to 1971–1999, precipitation statewide will increase 0%–15% by 2035 and 10%–35% by 2085 (Stewart et al., 2013). Precipitation in northwestern Alaska is predicted to increase 15%–30% by 2100, based on the A2 scenario (Stewart et al., 2013). While precipitation is expected to increase, fresh water availability is expected to decrease in Alaska due to increased water evaporation from higher temperatures and longer growing seasons (Chapin et al., 2014). For example, annual available water declined 55% over the past 50 years on the western Kenai Peninsula (USFWS, 2017).

While models do not predict a decrease in winter precipitation, there is considerable uncertainty regarding seasonal variability in precipitation predictions. Some studies predict changes to snowfall patterns, including later dates of first snows, earlier snowmelt, and a decline in high snowfall days. Models show that extreme precipitation events may also increase, particularly in the coastal regions (Walsh et al., 2014a).

2.4.3 Weather Patterns

Models show that extreme storm events may increase. Storm surges of 10 feet or more are predicted for many coastal communities in western Alaska during the next 50 years; some locations may see storm surges as high as 13 feet (UAF Sea Grant, 2014).

2.4.4 Sea Ice

The decline of sea ice is predicted to continue with increasing air and ocean temperatures, in addition to changes in atmospheric and ocean circulation (Stewart et al., 2013). If current trends continue, climate models predict significant declines in the extent of sea ice in Alaska. Models show that summer sea ice could disappear in the Chukchi Sea at some point during 2030–2050, and winter sea ice could decrease by 50% in the Bering and Chukchi Seas by the end of the century. Virtually ice-free northern waters in late summer are predicted by the 2040s (USGCRP, 2017; Chapin et al., 2014; Stewart et al., 2013). The predicted loss of sea ice and increased extreme storm events will likely increase coastal erosion, as sea ice typically protects the shoreline (EPA Climate Impacts, 2016).

2.4.5 Glaciers

Scientists expect continued glacial retreat in Alaska, though the scale of retreat is uncertain. Even if air temperatures stopped increasing in Alaska, glaciers could continue to respond to past warming trends for decades (NCA, 2014).

2.4.6 Permafrost

Projections show that permafrost will continue to thaw due to increased soil temperatures and that near-surface permafrost will disappear from much of Alaska by 2100 (Chapin et al., 2014; Jafarov et al., 2012; Stewart et al., 2013). As a result, the permafrost boundary is likely to move hundreds of miles northward by the end of the century (EPA Climate Impacts, 2016; Stewart et al., 2013). A loss of permafrost could also lead to the loss of surface water, which can lower the water table and decrease the depth of ponds and lakes (EPA Climate Impacts, 2016). Data also indicate that thawing permafrost releases carbon dioxide and methane and contributes to an increase in greenhouse gas emissions in Alaska (Commane et al., 2017). Scientists estimate that thawing permafrost worldwide could contribute to an increase of 0.13–1.69°F in global temperatures by 2300 (MacDougall et al., 2012).

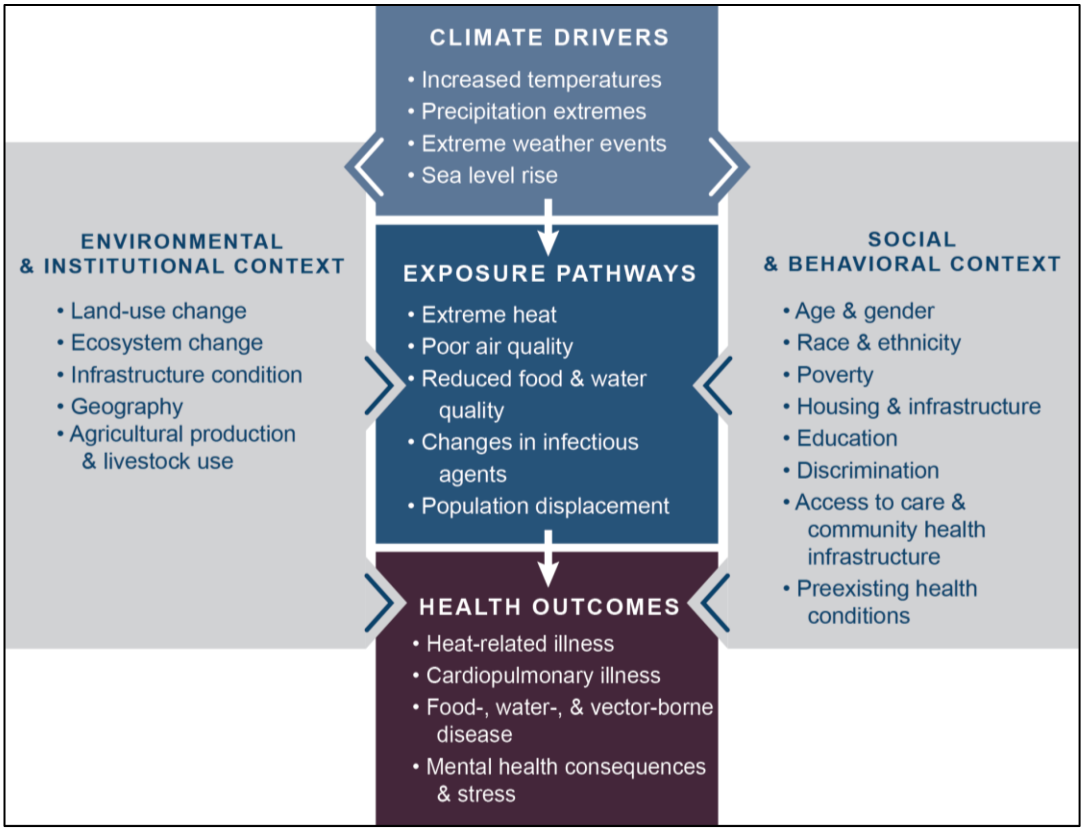
2.4.7 Sea Levels

Currently, the land surface in southern Alaska is rising faster than the global rise in sea level, leading to a continued decrease in sea level (O'Harra, 2010). Scientists anticipate that global sea rise will eventually exceed the rate of rising land surface in Alaska and that the State's entire coastline will eventually be affected by sea level rise, though the sea level rise is projected to be less than the global average (O'Harra, 2010; UAF Sea Grant, 2014; USGCRP, 2017). Much of Alaska's coastal land surface is predicted to rise 0.1–1.0 meter by 2100, whereas the projected global mean sea level (GMSL) rise is 0.3–2.5 meters (Sweet et al., 2017).

2.5 Climate Change and Health

Climate change can affect human health (Patz et al., 2014; USGCRP, 2016). Many international agencies (e.g., WHO, World Bank) and national groups (e.g., CDC, NOAA, and NASA) have discussed the current implications of climate change on human health and the potential for future health impacts. Although there are exceptions, climate change generally appears to exacerbate existing health challenges at both the community and individual levels (Smith et al., 2014). There are several different pathways by which climate change can affect health, including direct impacts such as injuries caused by fires or storm surges, and indirect impacts such as changes in quantity and quality of subsistence foods (Figure 3). Moreover, it is important to note that climate-associated health impacts on communities are magnified by additional social and economic stresses.

Figure 3. Climate Change and Human Health



Source: USGCRP, 2016; modified from U.S. Environmental Protection Agency

The potential human health impacts related to the climate change predictions for Alaska are discussed in this section. A health impact is a positive or negative change in a specific health outcome or health determinant that is characterized by *specific* health outcomes or determinants (not general statements about health status) and quantifiable data, whenever possible.

Each HEC contains health impacts that fit the criteria above. The following sections describe the interaction between the potential factors of climate change and human health. It is important to note that health outcomes and indicators in Alaska will change over time, regardless of climate change; this HIA focuses only on the potential health impacts from climate change. Future health impacts could be more or less substantial than what is discussed in this HIA, depending on changes in Alaska not directly tied to climate (e.g., economic changes).

2.6 Potentially Affected Communities

The Alaska HIA Toolkit defines a potentially affected community (PAC) as an area, community, or village where health impacts may occur. This HIA commonly refers to four regions of PACs where impacts due to climate change are predicted.

Climate change regions

Alaska: General predictions are available for Alaska (statewide) for most of the climate change indicators. Not all data are available at the regional level. This is noted where applicable.

Coastal: This region consists of communities where maritime strongly influences climate. In this HIA, the coastal region includes the Southeast (e.g., Juneau, Ketchikan, Sitka), South coast (e.g., Anchorage, Kodiak, Cordova), Southwest (e.g., Bethel, Dillingham, communities in the Aleutian Islands), and west-central (e.g., Nome, Kivalina, Kotzebue) portions of the state.

Interior: Interior Alaska is bounded by the Brooks and Alaska mountain ranges. This region experiences a continental climate with large temperature variability, low humidity, and relatively light precipitation (Stewart et al., 2013). Communities in this region include (among others) Fairbanks, Tanana, and Galena.

Northern: This region is north of the Brooks Range and is bordered on the north by the Arctic Ocean. This region is considered Alaska’s Arctic and has the lowest average annual temperatures in the state. Communities in this region include (among others) Utqiaġvik (formerly Barrow), Prudhoe Bay, and Anaktuvuk Pass.

3.0 PRIORITIZING HEALTH IMPACTS

The following sub-sections describe the interaction between the potential factors of climate change (based on the climate change predictions from Section 2.4) and provide examples of potential adverse health outcomes. Appendix 3 presents a comprehensive summary table of the potential interactions between climate change and health in Alaska.

The potential impacts identified in this section are reviewed according to climate change-specific health impact dimension criteria and are presented in a color-coded table in Section 3.2. Communities can identify and evaluate potential health impacts from climate change using a similar framework.

Populations of Concern

Climate change has impacts across various population groups in the United States and some populations may be particularly vulnerable to specific impacts. According to the World Health Organization, "vulnerability is the degree to which a population, individual or organization is unable to anticipate, cope with, resist and recover from the impacts of disasters" (Wisner and Adams, 2002). In terms of climate change, "vulnerability is the tendency or predisposition to be adversely affected by climate-related health effects, and encompasses three elements: exposure, sensitivity or susceptibility, and the capacity to adapt to or to cope with change" (USCGRP, 2016). Population groups that are particularly vulnerable to the impacts of climate change include people with low incomes, those with less literacy proficiency, indigenous groups, immigrant groups, children and pregnant women, the elderly, and persons with pre-existing or chronic medical conditions (Patz et al., 2014; USGCRP, 2016).

Rural Alaska has some of the highest rates of poverty in the United States as well as some of the highest costs for food and fuel. In 2014, the percent of residents living below the federal poverty level in the state was 10.2%, while the percent of people living below the federal poverty level in rural Alaska was over 60% (ACS Study, 2015). People who live in poverty may be particularly vulnerable to climate change because they have fewer resources to cope with adversity, relocate, evacuate, or respond in other ways (e.g., to increases in the cost of food and other resources; EPA Climate Impacts, 2016; NCA, 2014).

Alaska Native people living in rural areas may also be at increased risk for adverse health impacts from climate change, in part due to their close cultural ties to the land and subsistence food resources, such as salmon, caribou and whale (EPA Climate Impacts, 2016). Stresses to traditional practices, which encompass a way of life, as well as cultural, spiritual, and personal identity, could have significant social impacts in Alaska (ADEC, 2010); some villages report such changes have already begun (Bell et al., 2010; Cochran et al., 2013).

Children and the elderly are also important populations vulnerable to the impacts of climate change (Smith et al., 2014; USGCRP, 2016). Older adults may have added difficulty coping with climate change, due in part to mobility issues in a time of emergency, such as an extreme weather event. Children are also vulnerable due to mobility issues (they are reliant on others to care for them in disaster situations).

3.1 Potential Impacts by Health Effect Category

3.1.1 Mental Health and Wellbeing

Mental health and stress-related disorders are important health outcomes that are influenced by climate change (Luber et al., 2014; USGCRP, 2016). For example, climate change can affect mental health by causing solastalgia, the distressing sense of loss that people experience as a result of unwanted environmental changes that occur close to one's home (Albrecht et al., 2007), and associated pathologies such as anxiety, depression, and post-traumatic stress disorder that can result from acute events such as fires, floods, and storm surges, as well as more protracted changes such as thawing permafrost and coastal erosion (Patz et al., 2014; Watts et al. 2015; USGCRP, 2016). These effects disproportionately impact those living in low-resource settings, including indigenous groups (Berry et al., 2010). Climate change can also influence interpersonal violence, community conflict, and can impact mental health and wellbeing through changes in factors such as family structure, economic status, and cultural continuity (Cochran et al., 2013; USGCRP, 2016).

Psychosocial distress and associated health outcomes may also increase among emergency workers and first responders, due to the nature of their jobs. These workers respond to disasters involving death and injury and work in stressful environments, which put them at risk for post-traumatic stress disorder, depression, and panic disorder (USGCRP, 2016).

In Alaska, many residents have expressed concern and a feeling of depression related to the uncertainty of the scope and magnitude of potential climate change (ADEC, 2010). Residents have expressed anxiety about the potential impact of climate change on culture, subsistence resources, traditional knowledge and ways of knowing, infrastructure damage, the economy, community relocation, cultural and burial sites, recreational activities, future generations, and the 'Alaskan way of life' (ADEC, 2010). Based on the climate change predictions for Alaska, there may be continued impacts on mental health, community wellness, family structure, and "maladaptive" coping behaviors, such as alcohol use, substance abuse, and suicidality. Psychosocial distress, the stress and anxiety that arise over factors such as economic issues, relocation, and uncertainty over infrastructure stability, has already increased among some residents (Cochran et al., 2013). Psychosocial distress and its associated comorbidities is predicted to continue to increase as community relocation becomes more imminent, mental illness could be exacerbated because of factors such as decreased food security, damaged infrastructure and associated economic costs, water quality concerns, and extreme storm events (NCA, 2014; USGCRP, 2016).

Effects of Thawing Permafrost

Permafrost is found in over 80% of Alaska (Chapin et al., 2014; GAO, 2009). An estimated 100,000 Alaskans (roughly 14% of the Alaska population) live in areas sensitive to permafrost degradation (EPA Climate Impacts, 2016; USARC, 2013). As permafrost disappears and the landscape changes, roads may become damaged, subsistence resources may become more scarce and more difficult to access, and communities may need to relocate (Chapin et al., 2014; Cochran et al., 2013). Additional discussion on community relocation can be found in Sea Level Changes, below.

Thawing permafrost also increases the susceptibility of soil to erosion, which is a concern during intense storms along the coast, as well as in communities located along riverbanks. As the melted water in the soil drains away, the remaining soil becomes soft and porous, resulting in loss of surface water (including estuaries, ponds, lakes, streams, and rivers). When this soil comes into contact with waves or river currents, it easily erodes, sometimes in large quantities. Eroded coastline can lead to damaged infrastructure, including the potential loss of housing, medical clinics, water sanitation systems, roads, cultural and burial sites, and entire communities.

Damaged infrastructure, and uncertainty regarding the scope of thawing permafrost, could lead to psychosocial distress (e.g., anxiety or depression).

Effects of Sea Level Changes

Nearly 90% of Alaska Native communities are located on the coast (NPR, 2013). As sea levels continue to rise, several coastal Alaska villages have become inundated with tidal waters and have suffered extensive erosion and damaged infrastructure. Thawing permafrost has also led to coastal and riverbank erosion and infrastructure damage. In Shishmaref, for example, entire houses have been destroyed due to erosion. The United States Army Corps of Engineers (USACE) determined that Shishmaref and 183 of 213 (86%) other Alaska Native communities are at risk of flooding and erosion. According to the United States Government Accountability Office (GAO), 31 Alaska Native villages face imminent threats from flooding and erosion, both of which may worsen due to climate change (Bronen, 2011; GAO, 2009). Of these communities, at least 12 have decided to relocate (either partially or entirely), or at least consider the relocation process; several communities, such as Newtok, have already begun the relocation process (GAO, 2009). The threat and process of community relocation is stressful for residents and could result in a variety of adverse health outcomes related to psychosocial distress (Bronen, 2011).

Effects of Gradual Temperature Changes and Ecosystem Properties

In addition to extreme weather events causing psychosocial impacts, gradual climate change could also impact mental health. The gradual impacts of climate change may exacerbate existing mental health conditions or cause new ones (USGCRP, 2016). For example, climate change could lead to a distressing sense of loss—called solastalgia—as a person's land and way of life (culture) is changed (Smith et al., 2014). Studies on the mental health impacts from gradual and cumulative climate change are still limited and are less robust than the research on short-term extreme weather events, but there is some indication that long-term climate change could produce mental health impacts. The literature has focused on the effects of long-term temperature change, but some emerging studies show that changes to air quality, water quality, changing disease vectors, and food sources may also lead to adverse mental health outcomes (USGCRP, 2016).

Effects of Extreme Weather Events

Alaska is predicted to continue to experience more frequent and intense storms. Precipitation is expected to continue to increase, as shown by the climate change predictions for Alaska. Many people who have been affected by extreme weather events, such as floods, hurricanes, and wildfires, have experienced stress reactions and mental health consequences, such as post-traumatic stress and depression (EPA Health Impacts). Additional mental health effects include grief, increased substance abuse, and suicidal ideation (USGCRP, 2016). Highly destructive hurricanes have been associated with an increase in acute stress, post-traumatic stress, domestic violence, depression, and suicide in affected communities (USGCRP, 2016). These adverse mental health outcomes are particularly concerning for those who have experienced multiple disasters. For example, following Hurricane Katrina in 2005, veterans with pre-existing mental illness were 6.8 times more likely to develop additional mental illness compared to veterans without a pre-existing mental illness (Sullivan et al., 2013; USGCRP, 2016).

Anxiety and depression are also commonly reported outcomes of climate-related disaster events that involve significant life disruptions, including the loss of life, resources, and social support networks (USGCRP, 2016; Luber et al., 2014). Long-term depression and anxiety has been associated with flood events, as well as increased aggression in children (USGCRP, 2016; Ahern et al., 2005). Interpersonal violence often increases after extreme weather events, as well as suicidal behavior and substance abuse (Smith et al., 2014; USGCRP, 2016).

Effects of Weather Pattern Changes

With increased air temperatures, tourism, recreational, and subsistence activities may be impacted. Warmer temperatures can decrease the number of days when recreational snow activities such as skiing and snow machining can occur. Increased wildfires could impact hiking and other recreational activities in summer months. As tourism patterns change, communities that support themselves through these recreational activities may experience economic impacts. Alaskans who rely on these recreational activities for exercise and mental health may incur adverse health consequences if their recreational opportunities become more limited.

3.1.2 Accidents and Injuries

Climate change can cause direct and indirect impacts to the health outcomes and determinants related to accidents and injuries. Relevant health outcomes include unintentional fatal and non-fatal injuries, such as motor vehicle crashes and falls.

Effects of Temperature Changes

Climate change is projected to increase the frequency and duration of heat waves and the number of high-temperature days in Alaska (Stewart et al., 2013). In the past 60 years, average annual temperatures in Alaska have increased by 3°F and average winter temperatures have increased by 6°F (Chapin et al., 2014). On average, summers in Alaska have increased by more than 2.3°F over the past 50 years (Stewart et al. 2013), and the average annual temperatures in Alaska could be 2°–4°F higher by 2050 (Chapin et al., 2014). Alaska now experiences more extremely hot days and fewer extremely cold days than in previous decades (Chapin et al., 2014; Stewart et al., 2013).

Heat stress is the most direct health effect of a warming planet due to climate change (Patz et al., 2014). Prolonged exposure to heat can cause heat exhaustion, heat cramps, and heat stroke (Portier et al., 2010). Fatalities from extreme heat result from heat stroke and related conditions. Extreme heat also exacerbates preexisting conditions, such as cardiovascular, cerebrovascular, and respiratory diseases (Luber et al., 2014). Nationwide, heat-related deaths represent more deaths than from all other weather events combined, such as flooding or tornadoes (Luber and McGeehin, 2008; Patz et al., 2014; Portier et al., 2010). Roughly 700 deaths, on average, are attributed to heat-related causes in the United States annually (Portier et al., 2010). An estimated 35,000 excess deaths occurred during the European heat wave in 2003 (Patz et al., 2014).

While the temperatures in Alaska are not predicted to be nearly as high as in many other parts of the country, Alaskans may be more vulnerable to increasing temperatures than those living in other regions of the country due to a general lack of air conditioning or other means of cooling buildings and houses (Berner et al., 2005; Brubaker et al., 2013; Brubaker et al., 2011). One study found that cities with cooler climates tend to experience more heat-related deaths than those with warmer climates because populations in warmer climates can better acclimatize to heat and are more likely to have access to air conditioning (Portier et al., 2010). In the summer of 2013, for example, temperatures in Nondalton hovered around 70°–80°F for multiple weeks; there was a shortage of fans in the community, and several cases of heat stress were reportedly seen at the clinic (Brubaker et al., 2013).

Alaskan seniors and those with preexisting illnesses such as heart disease and diabetes may experience a higher burden of morbidity and mortality due to heat stress. Socioeconomic factors have also been found to determine vulnerability—economically disadvantaged and socially isolated people face higher burdens of death from heat (Portier et al., 2010). As such, rural Alaska communities may experience more challenges in adapting to warmer temperatures.

Effects of Extreme Weather Events

Extreme weather events such as droughts, floods and storms are predicted to increase with climate change and some reports suggest that change is already occurring. The frequency and intensity of extreme precipitation events is projected to increase in Alaska (Stewart et al., 2013). Flooding is typically the primary concern of extreme precipitation events and coastal storms, as floods are the second-deadliest of all the weather hazards in the United States (Patz et al., 2014; USGCRP, 2016).

Extreme precipitation events can also lead to fatal- and non-fatal injuries due to rock falls, mudslides, debris flow and avalanches. Extreme weather events, such as intense storms, could lead to increased risk of injury and death by more vessels capsizing from higher seas, more motor vehicle accidents caused by icier roads, etc. Extreme weather events may also cause infrastructure damage (Larsen et al., 2008). For example, buildings can collapse from heavy snow loads and supersaturated ground (IPCC, 2012). Infrastructure damage could lead to an increased risk of injury and death.

Storm surges—extreme high-water events caused by high winds and low atmospheric pressure—and stronger winter storms are predicted to increase in Alaska. Storm surges have already been causing increasing damage, particularly on the Bering Sea coast and in the Arctic (UAF Sea Grant, 2014). Damage includes receding shoreline due to erosion, infrastructure damage, and flooding. These consequences can lead to drowning, as well as fatal and non-fatal injuries (Brubaker et al., 2010; USGCRP, 2016).

In Alaska, a community-based surveillance study found that unintentional injury was significantly more likely to occur during months when participants reported unseasonable environmental conditions (e.g., heavier than average precipitation, increased variability in ice conditions); self-reported unintentional injuries were even more likely if participants had to change their travel plans (e.g., take a different route) in response to the unseasonable conditions (Driscoll et al., 2016)

Effects of Thawing Permafrost

The thawing and freezing cycles of permafrost often cause damage to the transportation infrastructure in Alaska, including roads, railroads, airstrips, and trails (EPA Health Impacts). Many of Alaska's roadways are built on permafrost. Roads and bridges can be damaged due to frost heaves or the subsidence of permafrost; motor vehicle accidents may result as unsuspecting drivers encounter this damage. Damaged roads, in addition to damaged airstrips and railroads, could also impede access to a number of facilities, including health clinics in emergency situations (Brubaker et al., 2012; Schwartz et al., 2014). See Section 3.1.8, Health Services Infrastructure and Capacity, for more information regarding the potential health impacts of damaged health facilities due to thawing permafrost.

Effects of Wildfires

Wildfires are predicted to continue to increase in size and intensity in Alaska due to increased temperature, as well as changes to precipitation and storm patterns (Brubaker et al., 2014; Chapin et al., 2014). Wildfires can directly cause fatal and non-fatal injuries—residents can be trapped in their homes, firefighters can be overpowered by flames, etc. Wildfire smoke can also impair driving visibility, which increases the risk of motor vehicle deaths and injuries (USGCRP, 2016). See Section 3.1.3 for an expanded discussion of the potential impacts of wildfires in Alaska, including potential air quality concerns.

Effects of Sea Ice Changes

As temperatures increase, sea ice distribution changes and ice thickness declines (Stewart et al., 2013). The reduction of sea and river ice can cause fatal and non-fatal injuries when people travel over thin ice and become stranded or break through the ice. Such accidents have been shown to cause a significant amount of deaths among Inuit populations (Berner et al., 2005). Hunters have reported a decrease in ice extent and thickness during key hunting times (Berner et al., 2005; Brubaker et al., 2012; Brubaker et al., 2010; Fleischer et al., 2013; NCA, 2014).

3.1.3 Exposure to Potentially Hazardous Materials

Climate change could impact air quality and change the way resources are transported in Alaska. This could change the exposure to potentially hazardous materials, such as air pollutants. Changes to the environment, such as thawing permafrost, could also lead to exposure to potentially hazardous materials. For example, thawing permafrost could expose previously buried contaminants. The key health outcomes considered in this HEC are increases and decreases in documented illnesses or exacerbation of illnesses commonly associated with pollutants of potential concern. These exposures may be mediated through inhalation, ingestion, or physical contact.

Effects of Thawing Permafrost

Permafrost contains large quantities of carbon—approximately twice the carbon that is currently in the Earth’s atmosphere (NCA, 2014). As permafrost thaws, microbes in the soil become more active and accelerate the breakdown of organic material. Greenhouse gasses such as carbon dioxide and methane are released into the air during this process (NCA, 2014). The release of greenhouse gases adversely impact air quality and further accelerates climate change (Schuur et al., 2015).

Additionally, as permafrost thaws, buried structures and materials can become exposed, leading to infrastructure damage, and the potential for increased exposure to contaminants. For example, thawing permafrost could subside and expose landfills and contaminated sites and increase the exposure to hazardous materials, such as asbestos, lead and other heavy metals, and organic contaminants (AMAP, 2003). Thawing permafrost could also damage existing infrastructure, such as pipelines, which could also lead to exposure to hazardous materials. In 2017, a well failure in Prudhoe Bay, Alaska led to an uncontrolled release of oil and gas into the environment. The event appears to have occurred as a result of a mechanical failure after thawed permafrost caused the ground below the well to sink, which placed extra pressure on the well (ADN, 2017). Though the permafrost thaw is believed to have been caused by hot production fluids in this particular incident, this event highlights the possibility of an increased exposure to hazardous materials due to thawing permafrost from a warming climate.

Effects of Global and Local Air Pollution

Climate change could impact air pollutant concentrations in a variety of ways. Climate influences weather components such as temperature, humidity, wind patterns and precipitation; each of these climate factors can influence air quality (NCA, 2014; USGCRP, 2016). Additional climate-driven metrological changes, such as wildfires and wind-blown dust, can also influence air quality. Poor air quality has been linked to adverse cardiovascular and respiratory health, premature death, and an increase in all-cause mortality (Lim et al., 2012; UNEP, 2011). This section focuses on the role of climate change in air pollution and associated human health outcomes.

Ozone

Ozone occurs naturally in Earth's stratosphere and is also formed by human-made activities. Ozone in the stratosphere is beneficial; it prevents harmful ultraviolet radiation from reaching Earth's surface. Ozone at ground level is a powerful oxidant and a lung irritant (USGCRP, 2016). Ground-level ozone is an air pollutant that is created by chemical reactions between nitrogen oxides (NOx) and volatile organic compounds (VOCs); ozone is a component of smog (EPA Ozone, 2016; Luber et al., 2014). Ground-level ozone is associated with adverse health outcomes, such as decreased lung function, increased premature deaths, and aggravated respiratory conditions (e.g., asthma, chronic bronchitis, and emphysema; EPA Ozone, 2016; Luber et al., 2014).

Ozone formation can increase with higher temperatures and sunlight. Ozone can also be affected by changes in weather patterns and humidity (Portier et al., 2010). Climate change may have already impacted ground-level ozone concentrations in some regions of the United States (Bloomer et al., 2009; Leibensperger et al., 2008; USGCRP, 2016). Worldwide, projections show that increasing temperatures from climate change could increase the number of days with unhealthy levels of ozone (EPA Climate Impacts, 2016).

However, ozone's warming effect on the Arctic, including Alaska, appears to be less significant than in other regions of the world. Modeling ozone changes in the Arctic has a lot of uncertainty when drawing conclusions about ozone levels and their effect on the Arctic (AMAP, 2015).

Particulate Matter (PM)

Particulate matter is a complex mix of solid particles and liquid droplets found in the air. PM can include, among other components, organic chemicals, metals, dust particles, and acids (i.e., nitrates and sulfate). Particulate matter is categorized by the size of particles. Particulate matter that is 10 micrometers (µm, PM_{10}) or smaller in aerodynamic diameter can be inhaled and enter a person's lungs. Fine PM ($PM_{2.5}$) is a subset of PM_{10} and refers to particles that are 2.5 µm or smaller in aerodynamic diameter, which are small enough to be inhaled deep into the alveoli in the lungs.

PM is known to cause adverse health effects. Recent literature shows that exposure to $PM_{2.5}$ has stronger associations to adverse health effects than PM of a larger size. Smaller particles can be inhaled more deeply into the lungs and are more likely to deposit in the lungs because they are not as readily expelled through sneezing or coughing.

Due to the complexity of particulate matter, researchers have not been able to predict whether climate change will increase or decrease fine particulate matter concentrations in the United States (EPA Climate Impacts, 2016). Humidity and temperature are known to play a role in the formation of $PM_{2.5}$ (Portier et al., 2010). Increased rainfall could decrease particulate matter suspended in the air (less dust), but other climate change factors could lead to an increase in PM, such as wildfires, melting glaciers (increased glacial dust), and wind patterns (EPA Climate Impacts, 2016).

In Alaska, there are several features of climate change that could lead to an increase in PM concentrations. Receding glaciers, for example, can lead to increased glacial dust. Strong winds, which may increase with climate change, can suspend glacial dust and lead to elevated ambient PM levels (primarily PM_{10}). This is already an issue in parts of Alaska; for example, PM_{10} in the Matanuska-Susitna Valley is primarily wind-blown silt from river basins. This phenomenon may worsen as glaciers continue to retreat. $PM_{2.5}$ could also increase in Alaska due to larger and more frequent wildfires (discussed in greater detail below).

Wildfires

Primarily due to increasing temperatures and changing precipitation and weather, Alaska's wildfire season is getting longer and fires are occurring more frequently and growing larger (UAF, 2013; USGCRP, 2017). Studies show that warmer temperatures could cause droughts, and therefore cause an increased risk of wildfires in various regions of the United States (Patz et al., 2014). Western states, including Alaska, are predicted to be particularly affected by more frequent large wildfires (Bennett et al., 2014; USGCRP, 2017). Record-breaking forest fire seasons have been seen in recent years; over 5 million acres burned in Alaska in 2015, one of the worst recorded fire seasons in the state (AICC, 2015). There have also been unusually large tundra fires in recent years. For example, the 2007 Anaktuvuk River fire burned 1,039 acres on the Alaskan tundra and released more carbon than had been absorbed by the entire circumpolar Arctic in the past 25 years (Chapin et al., 2014).

Adverse health outcomes are predicted to increase in association with increased wildfires in many regions of the United States (Luber et al., 2014; USGCRP, 2016). In addition to morbidity and mortality directly from wildfires (see Section 3.1.2: Accidents and Injuries), pollution exposure could also affect the population. Wildfire emissions can significantly exceed national air quality guidelines for several pollutants (such as PM). Wildfire smoke (comprised of particulate matter, nitrogen oxides, carbon monoxide, volatile organic compounds, and heavy metals such as mercury) has air pollution implications far beyond the actual location of the fire (Luber et al., 2014; Naeher et al., 2007). Communities near wildfires and thousands of miles downwind of fires can be exposed to wildfire emissions (smoke) ranging from days to months while the fire is active (Smith et al., 2014; USGCRP, 2016).

Exposure to smoke from wildfires has been associated with multiple adverse health effects, such as low birth weight, increased hospitalizations due to respiratory and cardiovascular conditions, and premature death (USGCRP, 2016). Worldwide, an estimated 339,000 premature deaths per year are attributed to air pollution from forest fires (Patz et al., 2014). Particulate matter can exacerbate existing conditions, such as asthma, COPD, and cardiovascular conditions (Delfino et al., 2009; Naeher et al., 2007; USGCRP, 2016). Wildfires are commonly associated with increased hospital admissions for exacerbated conditions, such as asthma and COPD. During the 2007 fire in San Diego, the odds of a person seeking emergency care increased by approximately 50% during periods of peak PM concentrations when compared with non-fire conditions (Thelen et al., 2013).

Climate modeling suggests that a warming climate might lead to more frequent and larger fires in the Arctic (ACIA, 2005). Future climate change may further increase the risk of wildfires in Alaska, thereby increasing wildfire emissions and negatively impacting human health (Chapin et al., 2014).

As large wildfires increase, more poor air quality events may result, potentially leading to exacerbations of pre-existing respiratory and cardiovascular illnesses.

Effects of Sea Ice Changes

A reduction in sea ice extent could make the Arctic Ocean more accessible for marine traffic. Shipping routes could increase, as well as oil and gas exploration and cruise ship travel in new areas. These changes could increase the risk of exposure to hazardous materials during a maritime-related accident, though the risk could also decrease given that marine vessels would have greater access to safer ice-free waters (NCA, 2014). Air and ocean pollution may also increase with more traffic in the Arctic Ocean; ports and marine vessels are major sources of black carbon and PM (Azzara and Rutherford, 2015).

Effects of Gradual Temperature Changes and Ecosystem Properties

Pesticides can be used to control nuisance or potentially disease-carrying pests, such as mosquitoes and ticks. They can also be used to protect agricultural crops from pests. Health effects vary depending on the type of pesticide. For example, some pesticides can affect the nervous and endocrine systems; some can cause lung, eye, or skin irritation; and some may cause cancer (EPA, 2017). Increased temperature, as well as other predicted ecosystem and weather pattern changes, such as increased precipitation, may facilitate pest migration to Alaska or an expansion of existing pest populations in the state (Rosenzweig et al., 2001). Pesticide use may increase in Alaska in response to changing pest populations, which could lead to increased human exposure to pesticides.

3.1.4 Food, Nutrition, and Subsistence Activity

Alaska state law defines subsistence use as "the noncommercial, customary and traditional uses of wild, renewable resources by a resident domiciled in a rural area of the state for direct personal or family consumption as food, shelter, fuel, clothing, tools, or transportation, for the making and selling of handicraft articles out of nonedible by-products of fish and wildlife resources taken for personal or family consumption, and for the customary trade, barter, or sharing for personal or family consumption" (State of Alaska, 2016: AS 16.05.940 [34]). The Alaska Federation of Natives (AFN) describes subsistence as "the hunting, fishing, and gathering activities which traditionally constituted the economic base of life for Alaska's Native peoples and which continue to flourish in many areas of the state today" (AFN, 2012).

Subsistence is part of a rural economic system, called a "mixed, subsistence-market" economy, wherein families invest money into small-scale, efficient technologies to harvest wild foods. Fishing and hunting for subsistence resources provide a reliable economic base for many rural regions. Subsistence is focused toward meeting the self-limiting needs of families and small communities (Wolfe and Walker, 1987; Fall, 2016). Subsistence fishing and hunting are important sources of employment and nutrition in almost all rural Alaska communities, regardless of race. Traditional and cultural activities also support a healthy diet and contribute to residents' overall wellbeing (ADF&G, 2016; Norton-Smith, 2016).

Rising food prices, challenges to food quality and quantity, and changing food distribution patterns are all factors that could be impacted by climate change (Luber et al,. 2014; Patz et al., 2014). Due to the specialized dietary patterns in Alaska with a heavy reliance on subsistence resources, changes to key food sources could lead to food insecurity and associated health consequences. Many Alaska communities have already reported various changes to subsistence harvest, such as salmon die-offs related to warmer ocean waters, shifting caribou migration, decline and range change in sea mammals, and increased variability in berry harvest (berry changes have been both positive and negative; Brubaker et al., 2014; Brubaker et al., 2012; Hupp et al., 2015).

Notable potential impacts of climate change on food, nutrition, and subsistence activity in Alaska include a northward shift in seal, walrus, and fish species; thinning sea and river ice, which can make harvesting wild foods more precarious; increasing ocean temperatures; and permafrost changes that could alter spring run-off patterns (Cochran et al., 2013). If these changes continue to occur, the consumption of local food sources might decrease (though the consumption of some local food sources could increase if a species moves into a new area).

Effects of Thawing Permafrost

In Alaska, permafrost changes could make travel and thus the harvesting of subsistence foods more difficult. Areas once stabilized by permafrost have started to subside, damaging transportation infrastructure and posing challenges for local populations harvesting subsistence resources (Norton-Smith et al., 2016). Subsistence harvesters in Kivalina report that thawing permafrost and related erosion have decreased stream water quality, resulting in a decrease in Arctic char populations. Salmon populations have increased in the area, but the traditional preference is for char (Brubaker et al., 2010). These challenges have led to smaller reported food harvests. If changes such as these continue to occur, the consumption of local food sources might decrease (though the consumption of some local food sources could increase if a species moves into a new area).

Thawing permafrost creates an additional challenge to the availability of traditional foods. Traditional ice cellars are failing in some Arctic communities (Brubaker et al., 2010b). Ice cellars, formed by digging a storage area into the permafrost, are an important component of subsistence food storage for some residents in the communities of Nuiqsut, Kivalina, Point Hope, Point Lay, Utqiaġvik, Wainwright, and Kaktovik. Alaska Native people have used ice cellars for thousands of years to store food and families have used the same ice cellars for generations (Brubaker et al., 2010). As soil temperatures increase and permafrost begins to thaw, ice cellars are more likely to fail and result in food spoilage. Cellar failure could lead to foodborne illnesses from consuming spoiled food (see Section 3.1.5) and could also lead to a crucial shortage of food for a household. Such shortages could increase food insecurity in communities (Brubaker et al, 2009b).

Effects of Gradual Temperature Changes and Ecosystem Properties

The various components of climate change, such as increasing temperatures, could impact ecosystems in Alaska. An example of such an impact is the expansion of plant species that were once limited to a specific part of the state due to temperature. Gradual changes to the ecosystem could also impact subsistence resources, and therefore potentially impact the availability of certain foods for residents (NCA, 2014). Some ecosystem changes could lead to population declines for some resources (e.g., less food available for caribou herds and the introduction of invasive species). Migration patterns of subsistence resources, such as caribou, have changed and may to change due to ecosystem changes. These migration changes could make harvesting subsistence resources more difficult in some communities (i.e., people will need to travel further to find a caribou), but could lead to more successful subsistence harvests in some areas (i.e., a resource moving into new habitat—such as deer) (Struzik, 2010). Warming temperatures might also lead to an increase in parasites in subsistence resources, such as caribou, which could potentially affect the availability of certain foods in Alaska (ADF&G, 2008; Bradley et al., 2005).

Ocean acidification, rising ocean temperatures, and declining sea ice are additional components of climate change that may interact to affect the location and abundance of marine fish, including those used for subsistence. Due to declining sea ice, subsistence hunters report needing to travel increasingly large distances to hunt marine mammals, such as bearded, spotted, ringed, and ribbon seals, whose reproduction and survival rates are known to fluctuate with climate changes (Ferguson et al., 2005).

3.1.5 Infectious Diseases and Toxins from Microorganisms

Researchers predict that climate change will cause a variety of temperature and ecosystem changes at both the global and local levels. Increasing temperatures and changing weather patterns can affect the incidence and spread of infectious diseases, especially vectorborne and waterborne diseases. Such implications include altered population size and range of hosts, vectors, and pathogens; duration of the transmission season; and outbreak timing and persistence (Parkinson et al., 2005). This section focuses on vectorborne, waterborne, and foodborne diseases that may be linked to climate change and are relevant to Alaska.

Vectorborne and Zoonotic Diseases: Effects of Temperature Changes, Extreme Weather Events, and Changing Weather Patterns

Vectorborne diseases are illnesses that are caused by pathogens and parasites in human populations (WHO, 2016). Common arthropod vectors include mosquitoes, ticks, and fleas. Climate change could impact vector ecology in several ways. Changes to weather patterns and the frequency of extreme weather events can affect vector population size, density, and survival rates. Climate change could also influence the reproduction and survival rate of pathogens in the host, as well as the size of the host population (Gage et al., 2008). Increases in temperature could also impact vector development; this may hinder or aid in vector survival, depending on the vector (ADEC, 2010). For example, an increase in temperature could allow for mosquitoes to survive longer in a previously inhospitable environment (Patz et al., 2014). In Alaska, increasing temperature and precipitation are potential driving factors for changes in the occurrence of vectorborne diseases.

Zoonotic diseases are diseases that can be spread between animals and humans. Since many people interact with animals frequently in their daily lives, some zoonotic diseases are common in human populations.

West Nile Virus

West Nile virus (WNV) was first observed in the United States in 1999. Since then, WNV has been documented in 48 states and has been spreading across the Canadian provinces as far west as Yukon Territory. Thus far, no locally-acquired cases of WNV have been recorded in Alaska.

The normal lifecycle of WNV involves mosquitoes and birds. When a mosquito feeds on an infected bird, it becomes infected with WNV and then transmits the virus by feeding on another bird, human, or horse. Humans and horses represent dead end hosts; probably because the level of viremia that develops is not high enough to allow mosquitoes that subsequently bite them to become infected (ADHSS, 2002). Of the 35 mosquito species known to carry WNV, several of those species are endemic or have been found in Alaska (e.g., *Aedes canadiensis, A. vexans, Culex pipiens,* and *C. restruans*) (ADHSS, 2002). However, given our relatively cool, short summers and brief mosquito season, experts feel that Alaska does not currently have favorable climatic conditions to support ongoing transmission of the virus, though this could change with a changing climate. The ideal temperature for WNV carriage in mosquitoes is at least 86° (30°C) over a 10 day period (NY ClimAid).

Climate change predictions for Alaska show an increase in temperatures across the state, particularly in the Interior and Northern regions. Summer temperatures in Interior Alaska already exceed 80°F for several days annually, and it is reasonable to assume that with the predicted temperature change for Interior Alaska, there is potential to meet this temperature requirement by the mid- to late-century (Chapin et al., 2014; Stewart et al., 2013).

Lyme Disease and Other Tick-borne Diseases

Ticks are restricted to specific geographic locations where climatic conditions, such as temperature and precipitation, are suitable for them to complete their life cycles (Gage et al., 2008). Tick habitat is also related to the abundance of host species, such as white tailed deer and white-footed mice. In the Lower 48, warmer air temperatures have increased the reproduction rate and range of the blacklegged ticks, *Ixodes scapularis* (deer tick) and *I. pacificus* (western blacklegged tick; EPA Climate Impacts, 2016). These ticks are vectors for the bacteria *Borrelia burgdorferi*, which causes Lyme disease (CDC Lyme Transmission, 2015).

There have been no known locally-acquired cases of Lyme disease in Alaska (Alaska does not currently have favorable climatic conditions to support the tick species that transmit the disease). Tick surveillance demonstrates that *I. scapularis* currently has an established range from the eastern U.S. into southern Manitoba, Canada (Bouchard et al., 2015). Climate-based models indicate that as temperatures increase, the *I. scapularis* population could continue to expand northward through Canada, and potentially to Alaska (Brownstein et al., 2005; Gage et al., 2008; McPherson et al. 2017). Moreover, recent surveillance efforts have identified *I. scapularis* on some Alaska dogs with recent travel outside of Alaska. There is no indication that *I. scapularis* is currently established in Alaska; however, further introduction of these ticks into the state could eventually result in an established population (Durden et al, 2016). Other non-native species can also survive if they are introduced to certain parts of the state (Woodford, 2012). For example, *Dermacenter variabilis* (the American dog tick, a vector for the pathogens that cause Rocky Mountain spotted fever, tularemia, Q fever, and bovine anaplasmosis) has been identified on Alaska dogs without a history of recent travel outside of Alaska. *D. variabilis* is not established in Alaska, but it does have eventual invasion potential, given the right set of climatic conditions (current northern range limit is below 52° North latitude in southern Canada [Dergousoff et al., 2013]; Durden et al., 2016; Woodford, 2012).

Rabies Virus

Rabies is a zoonotic disease caused by a family of viruses that infect mammals. The majority of animal rabies cases in the U.S. occur in wild animals, such as foxes, skunks, bats, and raccoons. Rabies is most commonly transmitted to humans via the bite of a rabid animal (CDC Rabies, 2016).

Rabies is enzootic (consistently present) among the fox populations of northern and western coastal Alaska. In Alaska, rabies infection most commonly occurs in foxes, although dogs, wolves, and bats occasionally become infected as well (ADHSS, 2011). Most cases occur in early fall through spring. During this time, foxes move inland from the sea ice. Climate changes could lead to conditions that support an increase in the Arctic fox population (Kim et al., 2014). Increasing temperature could facilitate an expansion of rabid Arctic fox populations, but predictions are complicated by modeled regional differences in precipitation (Kim et al., 2014). Decreased sea ice could limit the movement of Arctic foxes, which could lead to decreased opportunity for rabies transmission (Kim et al., 2014), but may also result in Arctic foxes foraging closer to villages and thereby might increase the likelihood of contact with humans and domestic pets.

Rabies from bats is common in the continental United States and several Canadian provinces. There are only six bat species in Alaska, and most have ranges that do not extend beyond southeast Alaska (ADHSS, 2016). The geographic range of bats is tied to several factors, including climate (particularly average temperatures; Kim et al., 2014). Of note for Alaska, the short duration of darkness in the summer limits foraging activities for bats, thereby limiting their northern range (ADHSS, 2006). This limiting factor would remain, regardless of climate change.

Echinococcosis

Echinococcosis is a zoonotic infection caused by tapeworms from the genus *Echinococcus*. Echinococcosis occurs sporadically in Alaska and reported cases have decreased in recent decades. Cystic echinococcosis, caused by infection with *Echinococcus granulosus*, has been reported in all regions in Alaska except the Aleutians. Alveolar echinococcosis, caused by infection with *E. multilocularis*, has only been reported in Alaska in the North Slope region and St. Lawrence Island. Warmer temperatures could support the expansion of foxes and voles, which are common carriers of *E. multilocularis,* though warmer temperatures might also make it harder for *E. multilocularis* eggs to survive (Parkinson and Evengård, 2009; Rausch, 2003; Jenkins et al., 2013).

Food- and Waterborne Diseases: Effects of Temperature Changes, Extreme Weather Events, and Ecosystem Properties

Climate change may alter the incidence of food- and waterborne disease by way of increased temperatures, extreme weather events, and changing availability of fresh food and drinking water. Increased temperatures can directly affect pathogens by influencing their survival, persistence, and virulence (ADEC, 2010; Fleury et al., 2006). For example, increased air temperatures may lead to thawing permafrost, which could impact the safety of traditional forms of food storage in Alaska (Brubaker et al., 2010b).

Extreme weather events, such as floods and droughts, can reduce the availability of safe drinking water, fresh food, and sewer services. Increased precipitation and associated runoff can also change the spread of pathogens that cause food and waterborne diseases (Parkinson and Butler, 2005). Flooding and heavy rainfall could cause overflows from sewage treatment facilities into fresh water sources and overflows could contaminate food crops with pathogen-containing feces (EPA Climate Impacts, 2016).

Botulism

Foodborne botulism is caused by ingesting the neurotoxin made by the bacterium *Clostridium botulinum*. Improperly canning, fermenting, aging, or putrefying foods can create an anaerobic environment, which promote the growth and toxin production of *C. botulinum*; this can happen at temperatures greater than 39°F (4°C; Parkinson and Butler, 2005). Cases of botulism in Alaska are relatively uncommon and have decreased in recent years, but the rate of foodborne botulism is higher in Alaska than anywhere else in the Nation (CDC Botulism, 2017). All foodborne botulism cases in Alaska have occurred among Alaska Native people who consumed traditional Alaska

Native foods (ADHSS, 2017b). These include "fermented" foods, dried foods, and traditionally prepared condiments, such as seal oil. Traditional foods, such as sea mammals, are not technically fermented because they lack adequate carbohydrates to enable fermentation; instead, these foods are usually putrefied (ADHSS, 2017b). Because of the temperature dependency of spore germination, it is possible that warmer ambient air temperatures in Alaska could result in an increase in cases of foodborne botulism if foods are not able to be properly prepared and stored in a manner that prevents spoilage (Parkinson and Evengård, 2009).

Paralytic Shellfish Poisoning

Paralytic shellfish poisoning (PSP) is a potentially fatal neuroparalytic condition that results from ingesting saxitoxin, a marine toxin produced by dinoflagellate algae. In the right conditions, saxitoxin accumulates in bivalve mollusks (e.g., mussels, scallops, and clams). Increasing temperatures promote harmful algal bloom (HAB) events in freshwater and saltwater, although PSP is a risk year-round (Paerl et al., 2011; Smith et al., 2014). Outbreaks of PSP have been reported world-wide and have increased in frequency and range. PSP cases occur in Alaska and could occur with greater frequency and broader range due to increasing ocean temperatures (Parkinson and Butler, 2005). HAB events can also involve domoic acid, a toxin produced by dinoflagellates that can cause amnesiac shellfish poisoning (ASP) when ingested by humans (NOAA Fisheries, n.d.). Climate change projections show HAB events in Puget Sound occurring 2 months sooner and lasting up to a month longer than at present. In Alaska waters, HAB events may also occur more frequently and last longer (UAF Sea Grant, 2014).

Giardiasis

Giardiasis is a diarrheal illness caused by the ingestion of *Giardia lamblia* cysts found in contaminated soil, food, or water, as well as by fecal-oral spread from an infected person (CDC Giardia, 2015). Alaska has some of the highest annual rates of giardiasis in the United States (Yoder et al., 2010; Painter et al., 2015). The incidence of giardiasis could increase with climate change as northern habitats become more suitable for animals that carry the protozoan (e.g., beaver; Brubaker et al., 2010; Parkinson and Evengård, 2009; Jenkins et al., 2013).

Other Gastrointestinal Illnesses

Vibrio parahaemolyticus is a leading cause of seafood-associated gastroenteritis in the United States. *V. parahaemolyticus* in Alaska has been associated with the consumption of raw oysters gathered in warm-water estuaries (McLaughlin et al., 2005). *V. parahaemolyticus* thrives in warmer water temperatures (e.g., >15°C; ADHSS, 2004b). Warm water temperature also appears to have led to Alaska's first documented outbreak of *V. parahaemolyticus* in 2004, which was a particularly warm summer (ADHSS, 2004). The prevalence of *V. parahaemolyticus* may increase in Alaska waters with increasing water temperatures, though there are effective means to prevent an outbreak. Following the 2004 outbreak, the Alaska Department of Environmental Conservation developed a control plan for *V. parahaemolyticus*. As part of this plan, shellfish harvesters must monitor water temperatures. If the temperature reaches ≥60°F, harvesters must take corrective action; such an action may include lowering oyster gear below the thermocline (temperatures <60°F; ADEC, 2017). The control plan and increased awareness of *V. parahaemolyticus* in the state are likely reasons why an outbreak in Alaskan waters has not occurred since 2004. (Note: potential impacts related to water and sanitation, such as gastrointestinal illness due to damaged water systems, will be addressed in Section 3.1.7, Water and Sanitation.)

Effects of Other Infectious Diseases and Toxins

Infectious Respiratory Diseases

The distribution of viruses with a wild bird host, such as influenza, could be impacted by climate change—particularly as ecosystems gradually change in response to factors such as changing temperatures (Berner et al., 2005). The impact of these potential factors on human cases of influenza, however, is unpredictable (Gilbert et al., 2008).

Other Toxins

Naturally occurring toxins may also be mobilized into the environment due to thawing permafrost, which could increase exposure to contaminants. In 2016, for example, an outbreak of anthrax occurred in the Siberian region of Russia and resulted in the hospitalization of dozens of people and the death of a child. Historically, many outbreaks of anthrax have occurred in reindeer and cattle in this region. Some researchers speculated that the cause of the outbreaks in 2016 was thawing permafrost that led to previously frozen and buried dead animals thawing and rising to the surface, and subsequently releasing anthrax spores that had been previously immobilized in the carcasses (NPR, 2016).

3.1.6 Non-communicable and Chronic Diseases

Climate change could also impact chronic non-communicable diseases due to lifestyle changes (e.g., leisure-time activity and diet) and aeroallergen and air quality changes (the potential effects of air pollution are addressed in Section 3.1.3).

Effects of Thawing Permafrost, Temperature Changes, and Ecosystem Properties

Changing Food Consumption Patterns

As discussed in Section 3.1.4, climate change could lead to a decrease in the consumption of subsistence foods and a decrease in food-secure households in Alaska. Shifting from subsistence foods can lead to an increase in the consumption of store-bought foods of lesser nutritional value (Johnson et al., 2008). Diets with more unhealthy and/or less nutrient-rich foods could lead to several chronic non-communicable conditions, such as obesity, diabetes, certain types of cancer, and cardiovascular disease (ADEC, 2010; Eyre et al., 2004). If diets change in Alaska due to climate change, rates of these chronic diseases could increase over time.

Changing Access to Recreational and Subsistence Activities

Warmer temperatures could decrease the number of days when recreational snow activities such as skiing and snow machining can occur, as well as some subsistence activities (e.g., hunting on the ice or snow). Increased wildfires could impact recreational activities (such as hiking) and subsistence activities during the summer months. Alaska residents who rely on these recreational and subsistence activities for exercise and mental health may be adversely affected if their opportunities become more limited.

Insect Bites and Stings

Increased temperatures may influence insect bites and stings in Alaska. Warmer average winter temperatures in Alaska might have already contributed to an increase in patients seeking health care for insect bite and sting reactions. In Alaska, there was a statistically significant increase in patients seeking care for insect reactions (e.g., yellowjacket stings) over a 14-year period (Demain et al., 2009). The most northern regions in the study had the largest percentage of increases in patients seeking health care for insect reactions and experienced the largest increases in winter temperatures, averaging at least 6°F. Researchers believe that warmer temperatures may have been a contributing factor to the increase in insect bites and stings (ADEC, 2010; Demain et al., 2009).

Effects of Aeroallergen Changes

Climate change could affect allergies and respiratory health as higher temperatures and changes in precipitation influence the abundance, seasonality, and distribution of aeroallergens (such as birch pollen; NCA, 2014). Warmer temperatures in Alaska could lead to greater pollen exposures due to earlier and longer pollen seasons. As a result, rates of allergic rhinitis (hay fever) and asthma could be impacted by these changes to aeroallergens.

A community-based surveillance study in Alaska observed that allergic asthma symptoms from outdoor sources were significantly more likely in months when participants reported unseasonable environmental conditions, such as pollen changes or increased precipitation (Driscoll et al., 2016; AMAP, 2017). In 2014 and 2016, tree pollen counts in Anchorage and Fairbanks were the some of the highest the world and may have been the result of an early, dry spring (ADHSS, 2017; ADN 2016). This increase in tree pollen counts may have resulted in more reported allergy symptoms in both communities (ADN, 2016).

3.1.7 Water and Sanitation

The World Health Organization (WHO) lists unsafe drinking water combined with inadequate sanitation and hygiene as one of the top 10 health risk factors leading to disease, disability, and death worldwide (Berner et al., 2005; WHO, 2009). The WHO estimated that these risk factors contribute to approximately 88% of the deaths from diarrheal diseases (CDC WASH, 2015). An estimated 900,000 people fall ill and up to 900 die each year in the United States from diseases resulting from drinking contaminated water (APHA, 2011). In Alaska, the lack of adequate sanitation is associated with increased transmission of communicable diseases such as respiratory infections, skin infections, meningitis, and gastroenteritis in rural communities (Berner et al., 2005; Hennessy, 2008; Wenger et al., 2010; Thomas et al., 2015).

Drinking water distribution in Alaska currently consists of several methods, including piped utility systems, community-haul, and self-haul (Warren et al., 2005). Sewage systems in Alaska include piped facilities, septic systems, pit privies (outhouses), community haul and self-haul. Approximately 80% of rural community housing units have in-home water and wastewater services (Thomas et al., 2015). The remaining 20% (approximately 30 communities) use alternative methods, such as honey buckets (a honey bucket is a container placed in the house and used as a toilet; disposal requires carrying the container outside to be emptied at a designated spot, which may or may not be a sewage lagoon; Berner et al., 2005).

Climate change could impact water and sanitation facilities, and rates of associated disease, in a number of ways. Flooding, thawing permafrost, increased temperatures, and changing weather patterns are all examples of climate change components that could impact human health. In Alaska, water and sanitation infrastructure damage has already occurred in some communities due to coastal and riverbank erosion, thawing permafrost, storm surges, and flooding (including flooding from spring ice breakup). Further damage to drinking water, wastewater, and/or storm water systems could adversely impact human health by way of facilitating waterborne diseases (such as giardiasis) and decreasing the availability and quality of water used for personal hygiene and drinking water.

Effects of Thawing Permafrost

Thawing permafrost can damage water and sewer infrastructure, leading to an increase in waterborne diseases, such as cryptosporidiosis and giardiasis. Thawing permafrost has already been implicated in damage to water and sewer systems in rural Alaska communities. Kwigillingok, for example, reported the loss of an aquifer due to the disappearance of permafrost (ADEC, 2010). As permafrost continues to thaw in Alaska, water and sewer infrastructure may suffer damage, which could increase waterborne and water-washed diseases (diseases caused by lack of clean water for washing, such skin and eye infections; ADEC, 2010).

Thawing permafrost could also lead to the drainage of surface water sources (AMAP, 2017). Lakes in permafrost regions in Alaska have already begun to change; some lakes have decreased in size and others have disappeared (Evengård et al., 2011). Because many communities in the Arctic rely on surface water sources, including Alaska's North Slope, changes to these sources could impact the availability of potable water and impact human health. For example, limited access to water is associated with an increase in skin infections and pediatric hospitalization rates for pneumonia, influenza, and respiratory syncytial virus infections (Wenger et al., 2010; Thomas et al., 2015; Hennessy et al., 2008).

Effects of Weather Pattern Changes

Increased precipitation, particularly heavy rainfall events, can overwhelm water and sewage systems, leading to waterborne infections (see Section 3.1.5 for an expanded discussion of waterborne disease and climate change; CDC, 2011; USGCRP, 2016; ADEC, 2010; Patz et al., 2014). In 1993, the largest outbreak of *Cryptosporidium* in the United States was preceded by the heaviest rainfall event in 50 years. This outbreak in Milwaukee caused approximately 403,000 illnesses and 50 deaths (MacKenzie et al., 1994; Patz et al., 2008). Extreme storm events have been tied to human illness in the Arctic (Evengård et al., 2011; Warren et al., 2005).

Extreme storm events can also damage infrastructure for drinking water, wastewater, and storm water systems (USGCRP, 2016). Heavy precipitation can lead to flooding and surface runoff and can increase pathogen loads in water sources and promote harmful algal blooms (USGCRP, 2016). Heavy precipitation events can also exacerbate existing issues with inadequate or deteriorating infrastructure.

Nationally, researchers predict that hurricanes and rainfall will increase in intensity, thus increasing the risk of flooding in coastal and inland regions. In Alaska, storms are predicted to increase in frequency and intensity. This predicted change, combined with increased coastal and riverbank erosion, could lead to damaged water and sanitation infrastructure, as well as contaminated surface water sources due to flooding. Storm damage to Kivalina in 2004, for example, damaged the community's leach field system for the washeteria (which is the only structure providing public showers, laundry facilities, and flush toilets, as Kivalina does not have piped water and sewer) and resulted in the closure of the washeteria for the entire winter (Brubaker et al., 2010). The rate of respiratory infections in Kivalina increased after 2004, possibly due to the washeteria's prolonged closure (Thomas et al., 2013). A community-based surveillance study in Alaska found that water insecurity (reduced amount of water usually used) was significantly more likely in months when participants reported unusual weather (Driscoll et al., 2016).

Effects of Sea Level Changes

Rising sea levels can increase coastal erosion, worsen storm surges and flood areas, and damage infrastructure (Patz et al., 2014). While sea levels are decreasing in some parts of Alaska, levels are increasing near some communities. Additionally, coastal erosion and storm surges are already challenges in some communities. Storm surges in vulnerable coastal regions could lead to sea water overtopping and contaminating freshwater sources (ADEC, 2010). As discussed in the climate change predictions for Alaska, the state may be adversely impacted once the rate of sea level rise exceeds the rate of rising land surface, though the scale and timing of this change is uncertain (O'Harra, 2010; UAF Sea Grant, 2014).

Effects of Temperature and Precipitation Changes

Though precipitation in the form of rain is expected to increase for much of Alaska, some models predict that the availability of potable water will decrease due to climate change (ADEC, 2010). For example, tundra lakes and ponds in some parts of Alaska have already been shrinking due in part to increased evaporation and increased drainage as permafrost thaws (Riordan et al., 2006). For a community-specific example, water operators in Point Hope reported that during the summers of 2007 and 2008, there was a disruption in drinking water treatment due to drought and a temperature-driven increase in organic material in an Arctic tundra lake, which was the source of drinking water for the community (Brubaker et al., 2009). There was no evidence of an impact to the rates of waterborne illness in the community during this incident; however, substantial increases in organic material can raise the cost of water treatment (due to more frequent filter changes), sometimes limiting a community's ability to provide safe drinking water (Brubaker et al., 2009).

3.1.8 Health Services Infrastructure and Capacity

Health services infrastructure and capacity refers to physical infrastructure, staffing levels, staff competencies, and technical capabilities of health care facilities. Access to health care and health care capacity is often influenced by natural disasters. This can occur if an influx in patients overwhelms health service capacity, thus limiting residents' access to health care. If large-scale incidents occur that involve multiple individuals, existing health services could be overwhelmed, as many clinics and regional health centers have limited capacity.

Currently, about half of all Alaska Native people reside in small communities that are isolated from regional hospitals and health centers due to large distances, weather events, and geographic barriers. Many of these communities are not accessible by road, and can only be accessed via boat, snow machine, or small aircraft.

Climate change could impact access to health care services. For example, thawing permafrost could damage a health clinic structure, a road accessing a clinic, or village runways. Extreme storm events and wildfire smoke can decrease access to health services. Communities without access to health care services may be adversely affected by climate variability and climate change (Frumkin et al., 2008; Smith et al., 2014).

Effects of Thawing Permafrost

Thawing permafrost could damage health care infrastructure and directly impact health care services—more people requiring medical assistance because of accidents and injuries due to failing infrastructure. Water supply systems and wastewater systems are further examples of infrastructure that could be damaged from thawing permafrost and result in adverse health effects.

Effects of Extreme Weather Events

In Alaska, scientists predict more frequent and intense storms due to climate change. As mentioned above, large-scale incidents, such as extreme weather events, could overwhelm existing health services, especially in communities where the capacity of health care resources are already strained. Extreme weather events could also preclude access to health services—e.g., storms can impede air and boat travel.

3.2 Key Potential Health Impacts by Health Effect Category

One initial step that local communities can take to prepare for climate change is to identify the potential health impacts that will be most relevant to their community and, for each identified impact, determine the expected timing and magnitude of the effect. Examples of criteria that could be used for this application include (a) potential time to impact, (b) geographic extent of the impact, (c) the number of people directly impacted, (d) the number of people impacted who might experience serious health problems, and (e) resources needed to adapt to the impact. The criteria can then be summarized and presented in a simplified visual format such as a tiered and color-coded table (e.g., Table 3). Next, communities can create a table that displays what the potential adverse health impacts of climate change might look like in their community for each health effect category to help prioritize adaptation strategies and resource needs (e.g., Table 4 presents a notional example of what such a table might look like on a statewide basis).

Table 3. Example of a System to Rank the Timing and Magnitude of Health Impact Dimension Criteria

	Timing and Magnitude		
Health Impact Dimension	**Lower**	**Intermediate**	**Higher**
Time to Impact	≥50 years	20–50 years	<20 years
Geographic Extent	Local	Regional	Statewide
Number of People Directly Impacted	Few	Intermediate	Many
Number of People Impacted who Might Experience Serious Health Problems	Few	Intermediate	Many
Resources Needed to Adapt/Respond	Few	Intermediate	Many

Table 4. Notional Example of Potential Adverse Health Impacts of Climate Change Statewide, by Health Effect Category*

Health Effect Category	Selected Adverse Health Impacts	Time to Impact	Geographic Extent	# of People Directly Impacted	# People Experiencing Serious Health Problems	Resources Needed to Adapt/ Respond
Mental Health and Wellbeing	Increase in solastalgia, anxiety, and depression due to the changing environment					
Accidents and Injuries	Increased heat stress and associated disorders					
	Increased accidents/injuries due to infrastructure damage					
	Increased accidents/injuries due to wildfires					
	Increased accidents/injuries due to extreme weather events (e.g., flooding)					
	Increased accidents/injuries due to unsafe ice conditions					
Exposure to Potentially Hazardous Materials	Increased cardiovascular disease morbidity/mortality due to air pollution (e.g., caused by wildfires)					
	Increased respiratory disease morbidity/mortality due to air pollution (e.g., caused by wildfires)					
	Increased exposure to hazardous materials (e.g., due to infrastructure damage, storm events)					
Food, Nutrition, and Subsistence Activity	Decrease in subsistence food consumption and food security (e.g., due to migration changes, increased costs of importing foods)					
Infectious Diseases and Toxins from Microorganisms	Increased morbidity/mortality related to vectorborne diseases					
	Increased morbidity/mortality related to zoonotic diseases					
	Increased morbidity/mortality related to food- and waterborne diseases (e.g., botulism, PSP, *Vibrio parahaemolyticus*)†					
Non-communicable and Chronic Diseases	Increased rates of chronic diseases such as obesity, diabetes, and hyperlipidemia due to changing lifestyles±					
	Increased rates of chronic respiratory diseases due to aeroallergens					
Water and Sanitation	Increased morbidity/mortality due to compromised access to water and sanitation facilities (e.g., infrastructure damage)					
Health Services Infrastructure and Capacity	Increased morbidity/mortality due to compromised access to health care (e.g., infrastructure damage)					

**Note*: This table was constructed as a notional example for Alaska communities to consider replicating when developing the community health component of their own climate change adaptation plans. As such, it should be viewed primarily as an instructional tool rather than a precise representation of the likelihood of specific health impacts due to climate change in Alaska. Creating a reliable table for the entire state would require more input from a wide range of subject matter experts and stakeholders.*

†This health impact focuses on illnesses that are not a direct result of compromised access to water and sanitation facilities, which are addressed in a subsequent category (Water and Sanitation).

±This health impact focuses on illnesses that are not a direct result of air pollution, which is addressed in a previous category (Exposure to Potentially Hazardous Materials).

3.3 Monitoring Recommendations and Adaptation Strategies

The monitoring recommendations and adaptation strategies discussed in this section are provided as suggestions based on the examples of potential health impacts identified in this statewide HIA.

3.3.1 Monitoring Recommendations

The monitoring recommendations provided here are intended to help characterize the adverse health impacts of climate change over time. Monitoring indicators and resources are listed to help decision-makers and other stakeholders develop surveillance strategies and identify agencies currently collecting the relevant health and environmental data. This section presents monitoring recommendations and resources for each HEC.

An effective monitoring strategy requires the development of a suite of measurable and objective indicators. Fortunately, numerous public health surveillance systems exist and robust sets of climate change indicators have been developed by agencies such as the U.S. Environmental Protection Agency (EPA Climate Change Indicators, 2016) and the Council of State and Territorial Epidemiologists (CSTE Climate Change Indicators, n.d.).

This HIA proposes health and environmental indicators to (1) characterize how well the state is performing for several health outcomes in each health effect category, and (2) monitor future change (Table 5). Table 5 also presents monitoring resources to help improve situational awareness related to potential climate change impacts. These resources are listed to help decision-makers and other stakeholders develop surveillance strategies and identify agencies currently collecting the relevant health and environmental data; however, agencies may not have designated staff for ongoing monitoring and the list of monitoring resources is not exhaustive. More resources will need to be developed to comprehensively monitor all potential indicators statewide. Where possible, this HIA identifies monitoring strategies that have been developed and tested by other state, federal, and international entities. For example, this HIA suggests monitoring many of the health and environmental indicators proposed and pilot tested as indicators by CSTE (CSTE Climate Change Indicators, n.d.).

Table 5. Proposed Health and Environmental Indicators and Monitoring Resources

Potential Impact	Health and Environmental Indicators	Examples of Existing Monitoring Resources
Mental Health and Wellbeing		
Increase in psychosocial distress (e.g., anxiety or depression) due to the changing environment	Health indicators • Hospital/clinic visits due to distress following a climate-associated event (e.g., flooding, storm surge, wildfire) Environmental indicators • Tidal gauges (to monitor sea-level rise)	Health resources • Alaska Trauma Registry (ATR) for injury trends: http://dhss.alaska.gov/dph/Emergency/Pages/trauma/registry.aspx • Alaska Health Facilities Data Reporting Program (HFDR) for hospital diagnoses trends: http://dhss.alaska.gov/dph/HealthPlanning/Pages/DischargeData.aspx Environmental resources • NOAA Sea Level Trends: http://tidesandcurrents.noaa.gov/sltrends/sltrends.html
Accidents and Injuries		
Increased heat stress and associated disorders	Health indicators • Deaths due to heat (number, rate)* • Hospitalizations due to heat (number, rate)* • ER visits due to heat (number, rate)* Environmental indicators • Daily maximum and minimum temperatures	Health resources • ATR for injury trends • Alaska HFDR for hospital diagnoses trends Environmental resources • Scenarios Network for Alaska + Arctic Planning (SNAP) for community profiles on observed and projected temperatures: https://www.snap.uaf.edu/tools-and-data/all-analysis-tools

Potential Impact	Health and Environmental Indicators	Examples of Existing Monitoring Resources
Increased accidents/injuries due to infrastructure damage (e.g., motor vehicle accidents)	Health indicators • Injuries and deaths from transportation (number, rate) Environmental indicators • Daily maximum and minimum temperatures • Soil temperatures	Health resources • ATR for injury trends • Alaska HFDR for hospital diagnoses trends • Alaska Department of Transportation (DOT) reports on fatal and nonfatal motor vehicle accidents Environmental resources • SNAP for community profiles on observed and projected temperatures
Increased accidents/injuries due to wildfires	Health indicators • Injuries and deaths due to wildfire (number, rate)* Environmental indicators • Air mass stagnation events (number)* • Total number of wildland fires* • Total number of acres affected by wildland fires*	Health resources • ATR for injury trends • Alaska HFDR for hospital diagnoses trends Environmental resources • BLM wildfire webpage: http://fire.ak.blm.gov
Increased accidents/injuries from extreme weather events (e.g., flooding)	Health indicators • Injuries and deaths due to severe storms (number, rate)* Environmental indicators • Meteorological event data, such as extent and timing of unusual events	Health resources • ATR for injury trends • Alaska HFDR for hospital diagnoses trends Environmental resources • SNAP for observed and projected extreme weather data • Alaska Shoreline Change Tool: http://maps.dggs.alaska.gov/shoreline/#-16434084:9589812:5
Increased accidents/injuries due to unsafe ice conditions	Health indicators • Injuries and deaths due to ice break-through events (number, rate) Environmental indicators • Ice thickness, timing of ice break-up and ice-free waters	Health resources • ATR for injury trends • Alaska HFDR for hospital diagnoses trends Environmental resources • SNAP for observed and projected sea ice coverage • Local Environmental Observer (LEO) Network for

Potential Impact	Health and Environmental Indicators	Examples of Existing Monitoring Resources
		postings by local observers and topical experts about unusual animal, environment, and weather events: www.leonetwork.org
Exposure to Potentially Hazardous Materials		
Increased cardiovascular disease morbidity/mortality due to air pollution (e.g., caused by wildfires)	Health indicators • Exacerbations of cardiovascular disease Environmental indicators • Annual average of PM_{10} and $PM_{2.5}$* • Days with PM_{10} and $PM_{2.5}$ in the unhealthy range* • Air mass stagnation events (number)* • Total number of wildland fires* • Total number of acres affected by wildland fires*	Health resources • Alaska HFDR for hospital diagnoses trends Environmental resources • Alaska Department of Environmental Conservation (ADEC) for $PM_{2.5}$ and PM_{10} monitoring • Community air monitoring programs
Increased respiratory disease morbidity/mortality due to air pollution (e.g., caused by wildfires)	Health indicators • Exacerbations of respiratory disease • Hospitalizations and ER visits due to allergic sensitizations and insect bites/stings Environmental indicators • Annual average of PM_{10} and $PM_{2.5}$ (number)* • Days with PM_{10} and $PM_{2.5}$ in the unhealthy range (number)* • Air mass stagnation events (number)* • Total # of wildland fires* • Total # of acres affected by wildland fires*	Health resources • Alaska HFDR for hospital diagnoses trends Environmental resources • ADEC for $PM_{2.5}$ and PM_{10} monitoring • Community air monitoring programs • Community pollen count monitors
Food, Nutrition, and Subsistence Activity		
Decrease in subsistence food consumption and food security (e.g., due to migration changes)	Health indicators • Subsistence harvest quantity per capita • Percentage of food secure households • Cases of nutritional deficiencies Environmental indicators • Number of successful hunts/caught salmon • Size of salmon runs	Health resources • Alaska Department of Fish and Game (ADF&G) subsistence harvest survey results and food security trends: https://www.adfg.alaska.gov/sb/CSIS/ • Alaska HFDR for hospital diagnoses trends Environmental resources • LEO Network for postings by local observers and

Potential Impact	Health and Environmental Indicators	Examples of Existing Monitoring Resources
	• Closure of hunting/fishing areas due to insufficient resources	topical experts about unusual animal, environment, and weather events: www.leonetwork.org • ADF&G fish counts: http://www.adfg.alaska.gov/sf/FishCounts/ • ADF&G subsistence harvest survey data
Infectious Diseases and Toxins from Microorganisms		
Increased morbidity/mortality related to vectorborne and zoonotic diseases	Health indicators • Cases of Lyme disease (number, rate)* • Cases of WNV (number, rate)* • Cases of *Vibrio parahaemolyticus* (number, rate) • Cases of animal rabies (number, rate) • Cases of giardiasis (number, rates) • Cases of echinococcosis (number, rate) Environmental indicators • Number of WNV positive mosquito pools* • Minimum infection rate (MIR) for WNV (MIR=WNV-positive pools per number of adult mosquitoes) tested)	Health resources • Alaska Section of Epidemiology (SOE) • Alaska HFDR for hospital diagnoses trends Environmental resources • Wide-scale mosquito sampling is not currently conducted in Alaska • Continued tick surveillance • LEO Network for unusual animal events
Increased morbidity/mortality related to food- and waterborne diseases (e.g., botulism, PSP, *Vibrio parahaemolyticus)*	Health indicators • Cases of PSP, *Vibrio parahaemolyticus*, domoic acid (number, rate) • Cases of botulism (number, rate) Environmental indicators • Number and length of harmful algal blooms (HAB events) • Ocean water and ambient air temperatures	Health resources • Alaska SOE • Alaska HFDR for hospital diagnoses trends Environmental resources • LEO Network • SNAP for community profiles on observed and projected temperatures • NOAA Coastal Water Temperature Guide: https://www.nodc.noaa.gov/dsdt/cwtg/
Non-communicable and Chronic Diseases		
Increased rates of chronic respiratory diseases due to aeroallergens	Health indicators • Allergic disease related hospital admissions (number, rate)* • Allergic disease related emergency discharges	Health resources • Alaska HFDR for hospital diagnoses trends Environmental resources

Potential Impact	Health and Environmental Indicators	Examples of Existing Monitoring Resources
	(number, rate)* • Hospital admissions due to asthma (number, rate) Environmental indicators • Date pollen season started and ended* • Length of pollen season (number of days)* • Days during pollen season when readings were elevated (number, percent)* • Pollen counts for the pollen season (mean, minimum, maximum)* • List of pollen types measured*	• LEO Network for unusual events
Water and Sanitation		
Increased morbidity/mortality due to compromised access to water and sanitation facilities (e.g., infrastructure damage)	Health indicators • Cases of childhood gastrointestinal illnesses, cryptosporidium, giardiasis (number, rate) Environmental indicators • Percentage of residents with access to adequate water and sanitation facilities	Health resources • Alaska HFDR for hospital diagnoses trends Environmental resources • ADEC Village Safe Water Program: http://dec.alaska.gov/water/vsw/index.htm
Health Services Infrastructure and Capacity		
Increased morbidity/mortality due to compromised access to health care (e.g., infrastructure damage)	Health indicators • Ratio of population to health care provider	Health resources • ADHSS Health Professional Shortage Area designations: http://dhss.alaska.gov/dph/HealthPlanning/Pages/primarycare/hpsa.aspx

**Part of nationwide CSTE Climate Change Indicators*

3.3.2 Adaptation Strategies

Adaptation as it relates to climate change is defined by the Intergovernmental Panel on Climate Change as the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2012; Watts et al., 2017). According to the Arctic Monitoring and Assessment Programme (AMAP), adaptation is also "an ongoing process encompassing awareness, understanding, mobilizing resources, building capacity, taking action, evaluating success and adjusting accordingly" (AMAP, 2017). Adaptation strategies related to health include efforts to reduce morbidity and mortality from climate-related causes (Watts et al., 2017). Communities can use the adaptation strategy examples below in developing their own climate change assessments, vulnerability assessments, and action plans. Overarching and HEC-specific adaptation strategy examples for communities are provided in Table 6 and 7. When possible, local values should be incorporated into the process of selecting adaptation strategies to increase the likelihood of successful implementation (Reid et al., 2014; AMAP, 2017).

Another important component of climate change adaptation is community resilience. In the event of a disaster, including climate-driven disasters such as large-scale flooding or a rapidly eroding shoreline, community resilience measures a community's capability of restoring the original pre-disaster state, as well as the capacity to cope with emerging post-disaster situations (Kais & Islam, 2016). Proactive community resiliency can reduce the vulnerability of residents and infrastructure to climate hazards and disasters (Community Resilience Building, n.d.). Policymakers that understand a community's resilience can better aid communities in avoiding or adapting to climate-related disasters (Kais & Islam, 2016). Building community resilience is typically a process whereby participants from various sectors (e.g., local government, tribal leadership, academia, corporations, and residents) work together to identify top hazards, current challenges and strengths, and prioritize actions to utilize resources in effective ways to recover from climate disasters (Community Resilience Building, n.d.).

Table 6. Overarching Adaptation Strategy Examples for Communities

Adaptation Strategies
Create local climate change advisory groups, assessments, and adaptation plans
Offer community members ample opportunity to relay their concerns about climate change and propose solutions
Develop and implement local community resilience plans (https://www.communityresiliencebuilding.com)
Include human health in community vulnerability assessments for climate change (for an example, see: http://www.georgetowntc.com/pdf/GeorgetownVulnerabilityAssessmentFinal.pdf)
Develop or update Small Community Emergency Response Plans (SCERP) and include potential climate-related disasters in the plans (https://ready.alaska.gov/Plans/SCERP).
Develop local and statewide health surveillance systems for selected climate change indicators
Provide informational resources to community members about the potential health impacts of climate change
Promote climate change research at local, regional, and statewide levels
Develop an ongoing catalogue of climate change studies and data gaps in Arctic and sub-Arctic populations
Assure sufficient public health workforce capable of performing climate change research, surveillance, and adaptation
Conduct risk communication, health education, and community outreach as needed

Table 7. Health Effect Category-Specific Adaptation Strategy Examples for Alaska Communities

Health Effect Category	Potential Adaptation Strategies
Mental Health and Wellbeing	• Raise awareness about solastalgia (the distressing sense of loss that people experience as a result of unwanted environmental changes that occur close to one's home) and promote strategies that mediate public risk perceptions, psychological and social impacts, coping responses, and behavioral adaptation (Resser et al. 2011) • Implement community-based strategies to promote mental health and wellbeing (e.g., https://www.preventioninstitute.org/taxonomy/term/124) • Implement and strengthen existing community-based behavioral health programs that aim to prevent mental/behavioral health problems (e.g., anxiety/depression, substance abuse, suicide, and violence prevention programs)
Accidents and Injuries	• Review architecture and engineering designs to ensure that infrastructure can withstand changes to the underlying permafrost and extreme weather events, and if not, consider ways to address the problem • Support surveillance and communication networks to warn community members of dangerous travelling conditions (e.g., thin ice, frost heaves in roads, storm surges) • Develop risk-appropriate storm shelters for Alaska communities • Develop a plan to create access to cooling centers during extreme heat events (e.g., in interior Alaska; often cooling centers are located in buildings with the capacity to provide cooler environments, such as an air-conditioned school or library)
Exposure to Potentially Hazardous Materials	• Review architecture and engineering designs to ensure that infrastructure can withstand changes to the underlying permafrost, and if not, consider ways to address the problem • Assess location-based vulnerabilities to wildfires, mitigate high-risk areas, and develop community response plans, such as the Firewise Community Program (http://forestry.alaska.gov/fire/firewise) • Develop a plan to create access to clean air centers during wildfires (https://www3.epa.gov/airnow/wildfire_may2016.pdf)
Food, Nutrition, and Subsistence Activity	• Establish community-based monitoring programs for subsistence resources, such as the Local Environmental Observer (LEO) Network and the Alaska Native Tribal Health Consortium (ANTHC) Rural Alaska Monitoring Program (RAMP); https://anthc.org/what-we-do/community-environment-and-health/climate-change-food-security) • Provide support for community freezers and other food safety programs to ensure access to safe and healthy traditional foods in Arctic communities • Conduct risk communication, health education, and community outreach regarding the presence of potential contaminants in subsistence foods
Infectious Diseases and Toxins from Microorganisms	• Support programs such as LEO Network, the One Health Group, and RAMP • Conduct ongoing, active monitoring for harmful algal blooms (HABs) • Expand surveillance efforts for cases of vectorborne diseases and presence of associated vectors
Chronic and Non-communicable Diseases	• Support monitoring efforts for seasonal patterns of respiratory and cardiovascular disease exacerbations that might be associated with wildfire smoke or aeroallergens
Water and Sanitation	• Review architecture and engineering designs to ensure piping infrastructure can withstand changes to the underlying permafrost, and if not, consider ways to address the problem • Collaborate with water utilities and water resource managers to assess expected performance of infrastructure and natural systems under changing climate conditions
Health Services Infrastructure and Capacity	• Review architecture and engineering designs to ensure health care infrastructure can withstand changes to the underlying permafrost, and if not, consider ways to address the problem

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5.0 APPENDIX 1: CLIMATE CHANGE INDICATORS

5.1.1 Temperature

This indicator focuses on air, surface, and ocean temperature patterns over time. Air temperature is measured at fixed locations over land and a mixture of ship- and buoy-based systems over the water. Thermometer and other instrument-based surface temperature records date back hundreds of years in some locations (NCA, 2014).

This indicator also examines trends in unusual temperatures from (a) the changes in average annual temperatures, (b) the size and frequency of prolonged heat waves, (c) unusually hot summer temperatures and cold winter temperatures, and (d) the changes in record high and low temperatures. To determine whether an observation is 'unusual' in terms of temperature, data are averaged over a particular month or season of interest; the coldest 10% of years are considered 'unusually cold', and the warmest 10% are considered 'unusually hot' (EPA Climate Change Indicators, 2016). Extremely hot and cold days are also reviewed; extremely hot days are considered the warmest 1% of daily high temperatures and extremely cold days are considered the coldest 1% of daily low temperatures (Stewart et al., 2013).

5.1.2 Precipitation

This indicator entails precipitation patterns, based on rainfall and snowfall measurements from land-based weather stations worldwide. Reliable statewide records are available for Alaska from 1925 to present (EPA Climate Change Indicators, 2016).

An extreme precipitation event is an episode of abnormally high rain or snow; the definition of 'extreme' varies based on location, season, and the length of the historical record.

5.1.3 Weather Patterns

This indicator includes climate features tied to weather patterns; season lengths, frequency/intensity of storms, and timing/amount of storm events are all considered. Roughly defined, weather is "the conditions of the atmosphere over a short period of time" (NASA, 2005). Climate, in comparison, is the behavior of the atmosphere over longer periods of time.

5.1.4 Sea Ice

This indicator describes the extent and age of Arctic sea ice. Data for this indicator are typically gathered by the National Snow and Ice Center using satellite imaging technology (EPA Climate Change Indicators, 2016). Extensive measurements of Arctic sea ice through satellite imaging began in 1979.

Sea ice extent is defined as the area of ocean where at least 15% of the surface is frozen. This indicator focuses on the average sea ice extent during peak freezing and peak melting months. Sea ice extent typically reaches its annual minimum in September and its maximum in March (EPA Climate Change Indicators, 2016).

The age of sea ice is determined by tracking ice as it moves over time through a combination of daily satellite images, wind measurements, and data from surface buoys (EPA Climate Change Indicators, 2016).

5.1.5 Glaciers

A glacier is a large mass of snow and ice, present year-round, which has accumulated over many years. Glaciers accumulate snow, which eventually becomes compressed into ice, and at lower elevations, the ice naturally loses mass because of melting and calving (ice breaking off and floating away). A glacier that does not increase or decrease in size when melting/calving is balanced by new snow accumulation (EPA Climate Change Indicators, 2016).

A world glacier inventory was created in the 1970s, based primarily on aerial photographs and maps. This inventory contains more than 100,000 glaciers, which cover an approximate area of 240,000 km^2 (UNEP, 2008).

This indicator describes the change in glacier mass balance, which is measured as the average change in thickness across the surface of a glacier. Glaciers provide visible evidence of changes in temperature and precipitation and can contribute to sea level rise if they lose more ice than they can accumulate through new snowfall (EPA Climate Change Indicators, 2016).

5.1.6 Permafrost

Permafrost is a layer of soil below the surface in which the temperature continuously remains below freezing (NWS, 2009). The upper layer of permafrost, the active layer, may thaw and refreeze seasonally. The active layer lies above the continually frozen permafrost layer. Permafrost consists of soil, rocks, and frozen water. Large quantities of carbon dioxide and methane are stored in permafrost (Chapin et al, 2014).

This indicator describes the extent of permafrost in Alaska. Permafrost extent is measured by soil temperature. The University of Alaska Fairbanks Geophysical Institute has been monitoring temperatures and depth of permafrost since 1976 (Stewart et al., 2013).

5.1.7 Sea Levels

This indicator encompasses trends in sea level based on measurements from tide gauges and from satellite imagery. Tide gauges measure relative sea level change along the coast and satellites measure absolute sea level change over the ocean surface. Many tide gauges have collected data for more than 100 years. Satellites have collected data since the early 1990s (EPA Climate Change Indicators, 2016). Sea level data for much of Alaska are available from 1975 to present (NOAA Tides and Currents).

6.0 APPENDIX 2: EVIDENCE FOR CLIMATE CHANGE OUTSIDE OF ALASKA

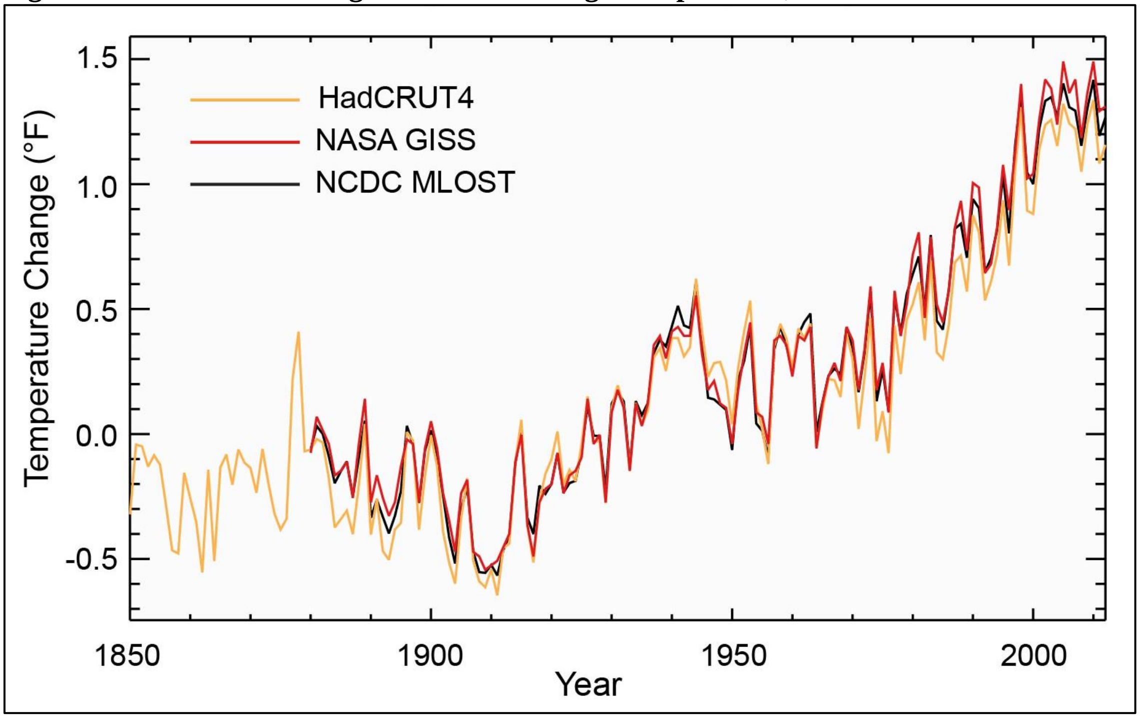
This section presents general changes in various climate change indicators and focuses on the global and national scale.

6.1.1 Temperature

Global Temperature Change

Globally, temperatures have increased by at least 1.5°F since 1880, based on information from three global temperature datasets (HadCRU4, NASA GISS, and NCDC MLOST; Figure A-1). Global temperature has risen at an average rate of 0.13°F per decade since 1901 (Walsh et al., 2014).

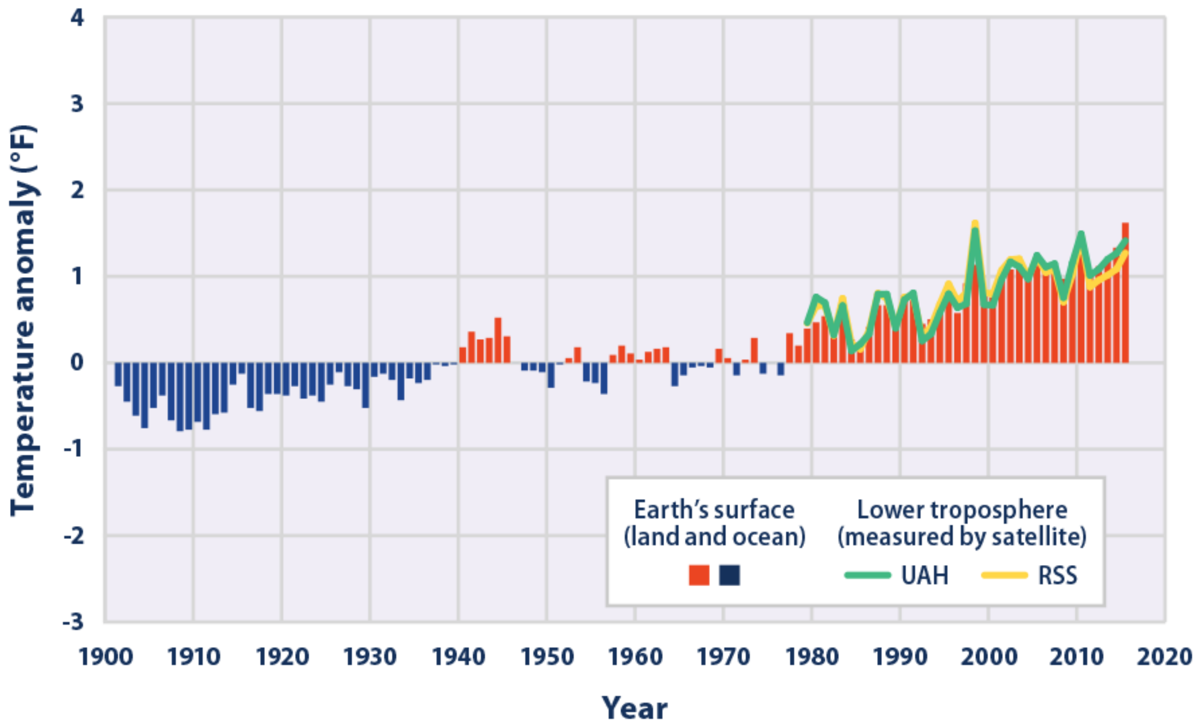
Figure A-1. Observed Change in Global Average Temperature, 1901–2012



Source: Climate Science Supplement, NCA 2014

Average temperatures have risen more rapidly since the 1970s (range: +0.26–0.43°F per decade; Figure A-2). The time period of 2005–2014 was the warmest decade since thermometer-based records began in the 1900s, and 2016 was the warmest year on record worldwide (EPA Climate Change Indicators, 2016; Blunden et al., 2017). Arctic regions have seen temperatures increase at twice the rate of temperatures elsewhere in the world (NCA, 2014).

Figure A-2. Average Change in Annual Temperatures Worldwide, 1901–2015



Data source: NOAA (National Oceanic and Atmospheric Administration). 2016. National Centers for Environmental Information. Accessed February 2016. www.ncei.noaa.gov.

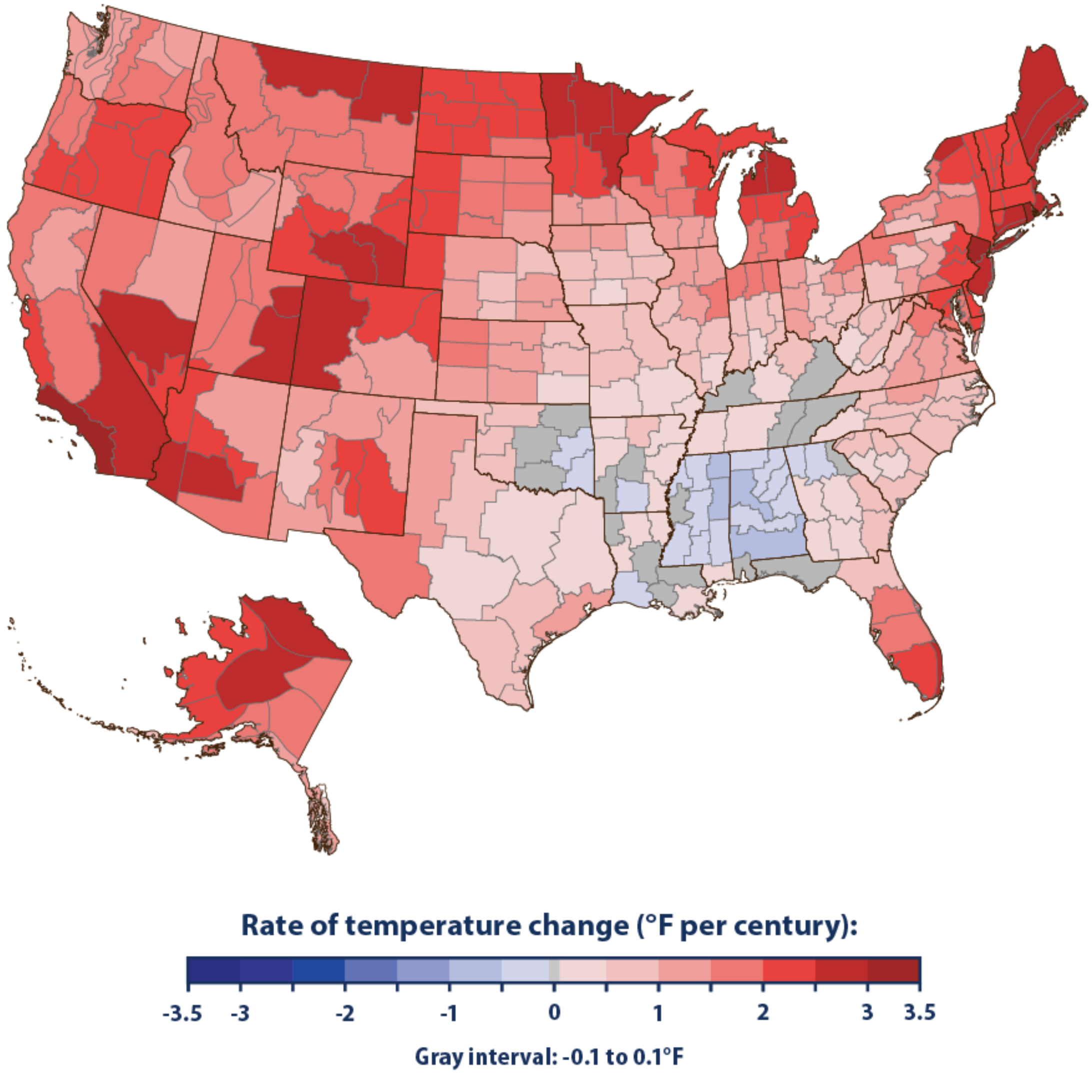
For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Source: EPA Climate Change Indicators, 2016

United States Temperature Change

In the United States, temperatures have risen more quickly in the North, the West, and in Alaska than in the rest of the country (EPA Climate Change Indicators, 2016). The average temperature in the United States has increased by 1.2–1.8°F for the period 1986–2016 relative to 1901–1960, at an average rate of 0.14°F per decade, though most of this change has occurred since 1970 (USGCRP, 2017; Walsh et al., 2014; EPA Climate Change Indicators, 2016; Figure A-3).

Figure A-3. Rate of Temperature Change in the United States, 1901–2015



*Alaska data start in 1925.

Data source: NOAA (National Oceanic and Atmospheric Administration). 2016. National Centers for Environmental Information. Accessed February 2016. www.ncei.noaa.gov.

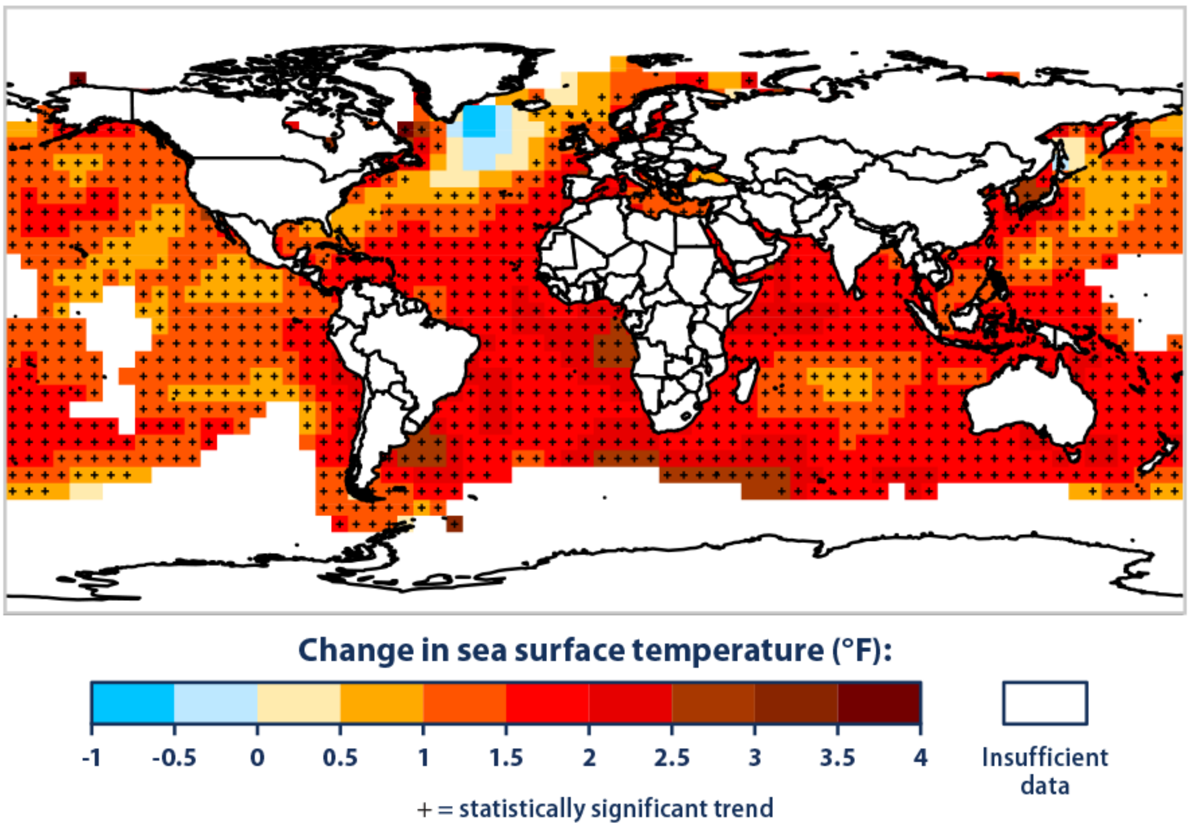
For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Source: EPA Climate Change Indicators, 2016

Ocean Temperature Change

The average sea surface temperature has increased globally. Temperatures rose at an average rate of 0.13°F per decade, from 1901–2014 (EPA Climate Change Indicators, 2016; Figure A-4).

Figure A-4. Change in Sea Surface Temperature, 1901–2015



Data sources:

- IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge, United Kingdom: Cambridge University Press. www.ipcc.ch/report/ar5/wg1.
- NOAA (National Oceanic and Atmospheric Administration). 2016. NOAA Merged Land Ocean Global Surface Temperature Analysis (NOAAGlobalTemp): Global gridded 5° x 5° data. National Centers for Environmental Information. Accessed June 2016. www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

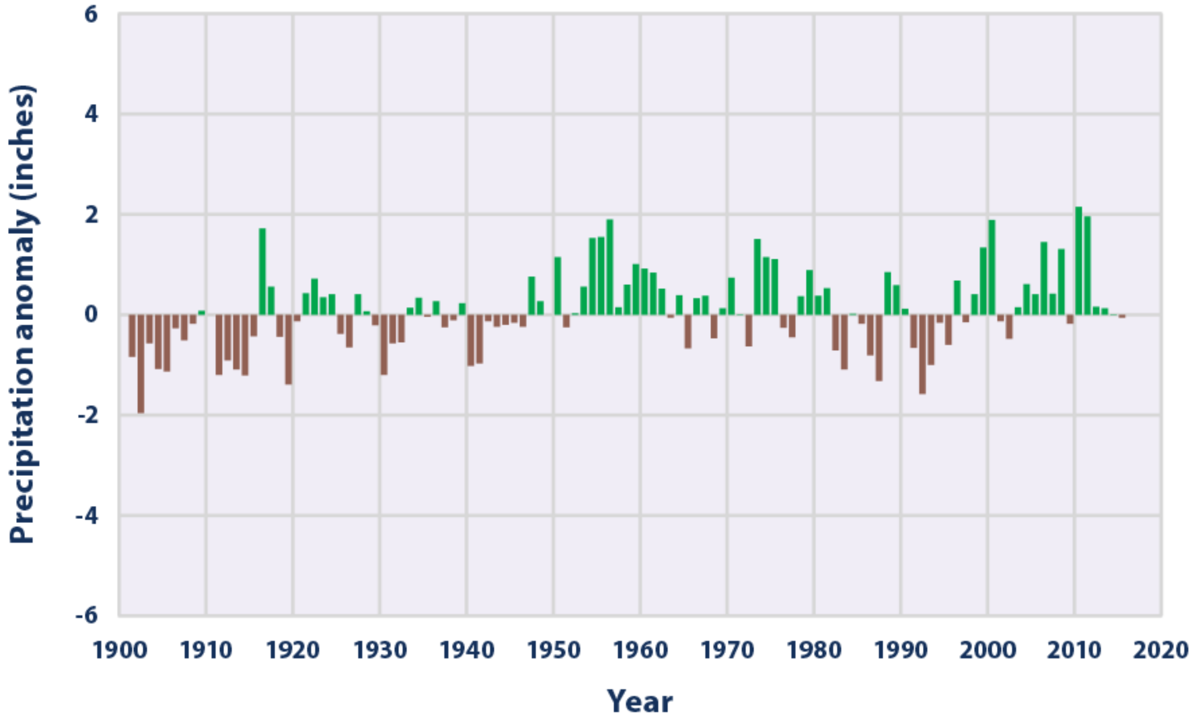
Source: EPA Climate Change Indicators, 2016

6.1.2 Precipitation

Global Precipitation Change

Overall, precipitation has increased worldwide (Figure A-5). While there are regions experiencing drought, the average global precipitation has increased at a rate of 0.08 inches per decade (EPA Climate Change Indicators, 2016).

Figure A-5. Precipitation Worldwide, 1901–2015



Data source: Blunden, J., and D.S. Arndt (eds.). 2016. State of the climate in 2015. B. Am. Meteorol. Soc. 97(8):S1–S275.

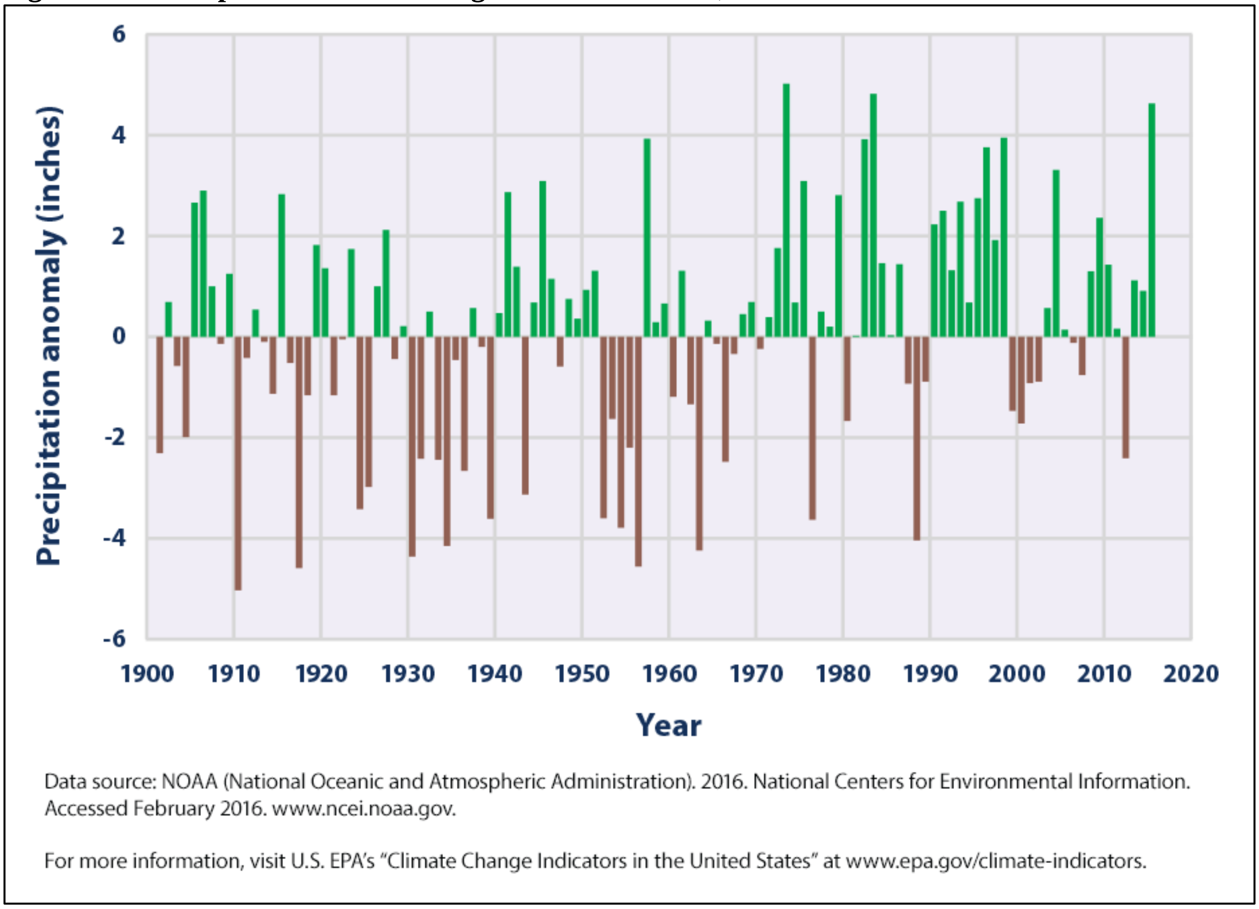
For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Source: EPA Climate Change Indicators, 2016

United States Precipitation Change

Precipitation in the contiguous United States has increased at a rate of 0.17 inches per decade (EPA Climate Change Indicators, 2016; Figure A-6).

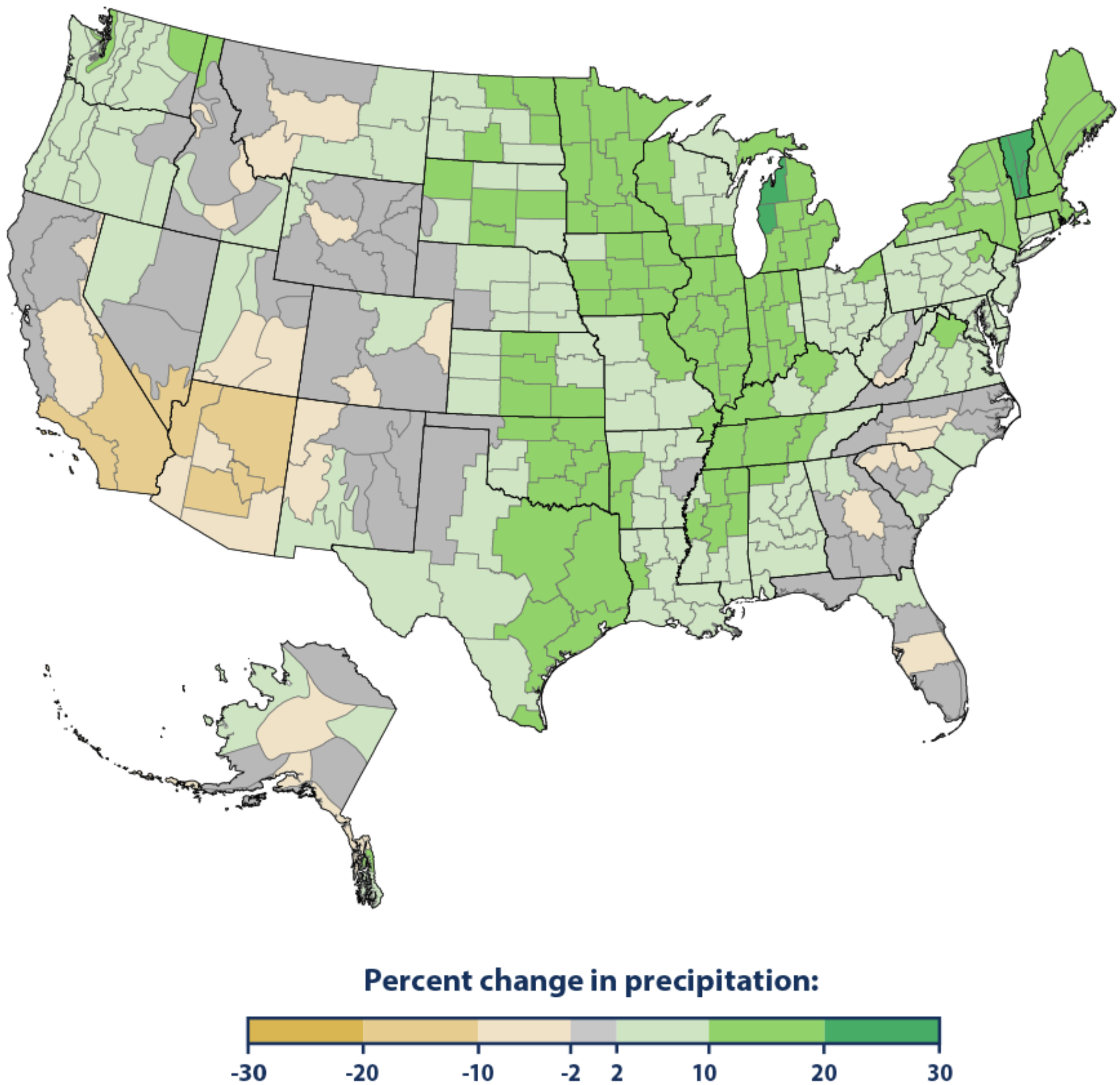
Figure A-6. Precipitation in the Contiguous United States, 1901–2015



Source: EPA Climate Change Indicators, 2016

While the United States has seen a general increase in precipitation, particularly in the Midwest and Northeast, areas such as the Southwest have experienced a decrease in precipitation (EPA Climate Change Indicators, 2016; Figure A-7).

Figure A-7. Change in Precipitation in the United States, 1901–2015



*Alaska data start in 1925.

Data source: NOAA (National Oceanic and Atmospheric Administration). 2016. National Centers for Environmental Information. Accessed February 2016. www.ncei.noaa.gov.

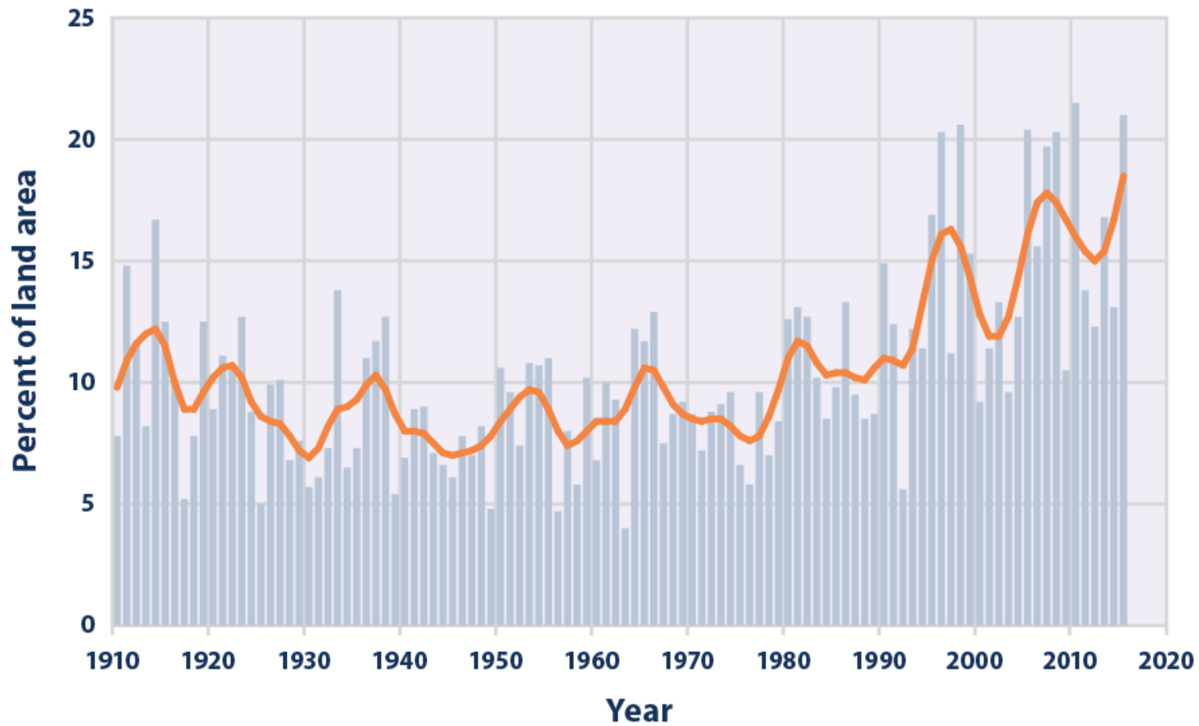
For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Source: EPA Climate Change Indicators, 2016

Heavy Precipitation

Recently in the United States, a larger percentage of precipitation has come from intense single-day events (EPA Climate Change Indicators, 2016; Figure A-8).

Figure A-8. Extreme One-day Precipitation Events in the Contiguous 48 States, 1910–2015



Data source: NOAA (National Oceanic and Atmospheric Administration). 2016. U.S. Climate Extremes Index. Accessed January 2016. www.ncdc.noaa.gov/extremes/cei.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Source: EPA Climate Change Indicators, 2016

6.1.3 Sea Ice

Sea ice forms at approximately 28.8°F and melts from exposure to sunlight, warm air, and ocean currents. Arctic sea ice has been declining since satellite measurements began in 1979. Typically, sea ice reaches its minimum in September in the Arctic (Stewart et al., 2013). Sea ice extent in the Arctic has decreased at an average rate of 3% per decade. Models predict seasonally nearly ice-free northern waters by the 2030s or 2040s (Doney et al., 2014; USGCRP, 2017).

6.1.4 Glaciers

Globally, the amount of ice contained in glaciers has been declining every year for more than 20 years. This lost mass partially contributes to the observed rise in sea level (Hartmann et al., 2013). Current climate change scenarios predict continued rapid glacier retreat and may possibly lead to deglaciation of many areas in the next several decades (UNEP, 2008).

6.1.5 Sea Levels

The Global Mean Sea Level (GSML) has risen by about 7–8 inches since the late 1800s (Walsh et al., 2014; USGCRP, 2017) and has been rising at a rate of 0.14 inches per year since the early 1990s (Walsh et al., 2014; Rhein et al., 2013). According to the Intergovernmental Panel on Climate Change (IPCC), the rate of sea level rise from 1993–2003 was significantly higher than the average rate in the preceding 80 years (Rein et al., 2013). Models predict that if warming continues unabated, oceans could rise 0.3–0.6 feet by 2030, 0.5–1.2 feet by 2050, and 1.0–4.3 feet by 2100 (USGCRP, 2017).

7.0 APPENDIX 3: POTENTIAL HEALTH IMPACTS OF CLIMATE CHANGE, BY CLIMATE CHANGE FACTOR

Climate Change Factor	Health/Environmental Determinant	Potential Health Impact
Mental Health and Wellbeing		
Temperature/ Ecosystem changes	• Changes to subsistence resources, transportation infrastructure, etc. • Changing recreational opportunities (positive and negative) • Changes to economic opportunities	• Increased cases of stress disorders, anxiety, depression • Increased rates of "maladaptive" coping, e.g., increased substance/drug (including alcohol) use • Increased economic indicators, such as median household income
Weather pattern changes	• Infrastructure damage due to extreme weather events	• Increased cases of stress disorders, anxiety, depression • Increased rates of "maladaptive" coping, e.g., increased substance/drug (including alcohol) use
Permafrost changes	• Infrastructure damage	• Increased cases of stress disorders, anxiety, depression • Increased rates of "maladaptive" coping, e.g., increased substance/drug (including alcohol) use
Sea level changes	• Erosion • Infrastructure damage	• Increased cases of stress disorders, anxiety, depression • Increased rates of "maladaptive" coping, e.g., increased substance/drug (including alcohol) use
Accidents and Injuries		
Temperature/ Ecosystem changes	• Decreased exposure to cold • Increased high temperature days • Increased wildfires (may decrease in some locations)	• Decrease in fatalities from cold-related exposures • Increase in heat-related hospitalizations • Increased burn injuries or deaths
Weather pattern changes	• Increase in flooding events • Potential increase in rock slides and avalanches (due to extreme weather events)	• Increase in injuries or drownings • Increase in accidents/injuries from rock slides, avalanches, etc.
Sea ice changes	• Increased "break-through" on waterways • Decreased sea ice extent	• Increase in fatalities due to drowning • Increased animal bite/exposures (with changes to wild fox habitat range)
Permafrost changes	• Increased damage to transportation infrastructure	• Increased accidents/injuries

Climate Change Factor	Health/Environmental Determinant	Potential Health Impact
Exposure to Potentially Hazardous Materials		
Temperature/ Ecosystem changes	• Increased ozone • Increased rates, range and season for allergens • Increased dust • Increase of PM_{10} • Increase of $PM_{2.5}$ • Increase of CO_2	• Increased rates of respiratory disease • Increased rates of cardiovascular disease
Sea ice changes	• Increased exposure to spills • Increase of PM_{10} • Increase of $PM_{2.5}$ • Increase of CO_2 • Increase of NOx • Increase of SOx • Increase of black carbon	• Increased morbidity/mortality from exposure to hazardous materials (air, water, and soil hazards; natural and man-made) • Increased rates of respiratory disease • Increased rates of cardiovascular disease
Permafrost changes	• Increased mobilization and exposure to ground contamination (e.g., legacy wells, contaminated sites, salt water intrusion) • Increased potential for infrastructure damage (e.g., pipeline damage) and exposure to related materials (e.g., diesel) • Increased contamination levels in subsistence resources • Decreased air quality • Decreased surface and ground water	• Increased morbidity/mortality from exposure to hazardous materials (air, water, and soil hazards; natural and man-made • Decreased consumption of local food sources • Decreased access to health facilities (due to damaged infrastructure • Decreased rates of adequate water and sewer services (due to damaged infrastructure)
Food, Nutrition, and Subsistence Activity		
Temperature/ Ecosystem changes	• Changes to food security (changes in availability of local food sources) ○ Crop yields ○ Animal migration patterns ○ Plant diseases ○ Food costs • Decreased food quality (increased presence of contaminants • Decreased food quantity (increased presence of contaminants) ○ Decreased food security (increased presence of contaminants)	• Changes to consumption of local food sources (could increase or decrease, depending on resource)

Climate Change Factor	Health/Environmental Determinant	Potential Health Impact
Sea ice changes	• Changes to food security (changes in availability of local food sources)	• Decrease in consumption of local food sources • Decreased access to safe food resources
Permafrost changes	• Decreased food security (decreased ability to store food [ice cellars, drying fish, etc.], decreased access to resources)	• Decrease in consumption of local food sources • Decreased access to safe food resources
Infectious Diseases and Toxins from Microorganisms		
Temperature/ Ecosystem changes (esp. changes in vector ecology); weather pattern changes	• Increased zoonotic diseases/vectors (e.g., bats) • Increased vectorborne diseases/vectors (e.g., mosquitoes, ticks) • Increased foodborne diseases • Increased waterborne diseases (flooding, etc.) • Introduction of new diseases	• Increased rates of vectorborne diseases e.g., rabies, West Nile Virus, Lyme disease • Increased rates of foodborne diseases e.g., PSP, domoic acid, *Vibrio parahaemolyticus*, botulism • Increased rates of waterborne diseases e.g., cryptosporidiosis, giardiasis
Permafrost changes	• Increased breeding ground for mosquitoes • Decreased adequate water and sewer services in households (due to damaged infrastructure) • Exposure to grave sites	• Increased rates of vectorborne diseases, e.g., West Nile Virus • Increased rates of waterborne diseases, e.g., cryptosporidium, childhood gastrointestinal illnesses
Non-communicable and Chronic Diseases		
Temperature/ Ecosystem changes	• Changing access to and availability of subsistence resources (shift from subsistence food consumption) • Changing access to recreational activities (could increase or decrease, depending on the activity • Insect bites/stings (e.g., wasp, bee) • Increased fungi, molds, etc. • Increased production of pollen and other allergens • Changes to abundance and seasonality of allergens	• Decrease in consumption of local food sources • Increased rates of obesity • Increased rates of diabetes • Change in leisure time physical activity (could increase or decrease) • Increased allergic sensitizations • Increased asthma episodes • Increased rates of respiratory disease
Permafrost changes	• Decreased food security (decreased ability to store food [ice cellars, drying fish, etc.], decreased access to resources)	• Change in consumption of local food sources (could increase or decrease, depending on resource) • Increased rates of obesity • Increased rates of diabetes

Climate Change Factor	Health/Environmental Determinant	Potential Health Impact
	• Changing access to and availability of subsistence resources • Changing access to recreational activities (could increase or decrease, depending on the activity	• Change in leisure time physical activity (could increase or decrease)
Water and Sanitation		
Temperature/ Ecosystem changes	• Decreased water availability and quality (due to salinization of aquifers) • Increased algal blooms	• Decreased availability and quality of drinking water • Decreased surface water quality • Increased rates of PSP, *Vibrio parahaemolyticus*, domoic acid, etc.
Weather pattern changes	• Overwhelmed sewage systems • Damaged water and sanitation services • Decreased percentage of households with water and sewer service	• Increased rates of waterborne diseases (e.g., cryptosporidiosis, childhood gastrointestinal illnesses)
Permafrost changes	• Damaged water and sanitation services • Decreased percentage of households with water and sewer service	• Increased rates of waterborne diseases e.g., cryptosporidiosis, childhood gastrointestinal illnesses
Sea level changes	• Contamination of groundwater and/or surface water	• Increased rates of waterborne diseases (e.g., cryptosporidiosis, childhood gastrointestinal illnesses)
Health Services Infrastructure and Capacity		
Temperature/ Ecosystem changes	• Increased strain on health care infrastructure	• Decreased access to comprehensive care
Weather pattern changes	• Damage to health care infrastructure (due to extreme weather events) • Damage to transportation infrastructure • Damage to specific health clinics (due to extreme weather events)	• Decreased access to comprehensive care • Decreased number of health clinics • Decreased capacity of emergency services
Permafrost changes	• Damage to health care infrastructure • Damage to transportation infrastructure (esp. ice roads) • Damage to health clinics	• Decreased access to comprehensive care • Decreased number of health clinics • Decreased capacity of emergency services